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Otsuki

(10) **Patent No.: US 6,530,646 B2**
(45) **Date of Patent: Mar. 11, 2003**

(54) **COLOR PRINTING USING A VERTICAL NOZZLE ARRAY HEAD**

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(21) Appl. No.: **09/983,868**

(22) Filed: **Oct. 26, 2001**

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Related U.S. Application Data

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(30) **Foreign Application Priority Data**

Dec. 24, 1998 (JP) 10-366274

(51) **Int. Cl.**[7] **B41J 2/15**
(52) **U.S. Cl.** **347/41**; 347/15
(58) **Field of Search** 347/15, 43, 41, 347/16

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,209,987 B1 * 4/2001 Kayayama 347/43

FOREIGN PATENT DOCUMENTS

JP 403189167 * 8/1991 .... 347/43

* cited by examiner

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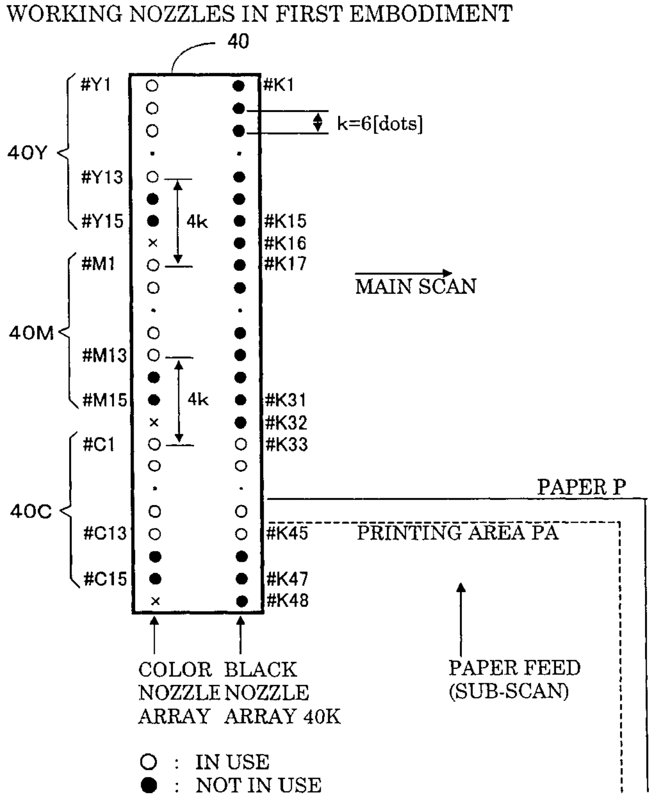
(74) *Attorney, Agent, or Firm*—Oblon, Spivak, McClelland, Maier & Neustadt, P.C.

(57) **ABSTRACT**

The sub-scanning drive section includes a first sub-scanning drive mechanism of a relatively high precision, and a second sub-scanning drive mechanism of a relatively low precision. An actuator **40** of a print head **36** is provided with a black nozzle array **40**K and a color nozzle array. The color nozzle array is arranged so that at an arbitrary point on a print medium yellow dots are formed after dots of other chromatic colors. During color printing, when the print medium is being fed at a low precision in the vicinity of the trailing edge of the print medium, only the yellow nozzles are used to form dots.

10 Claims, 28 Drawing Sheets

WORKING NOZZLES IN FIRST EMBODIMENT



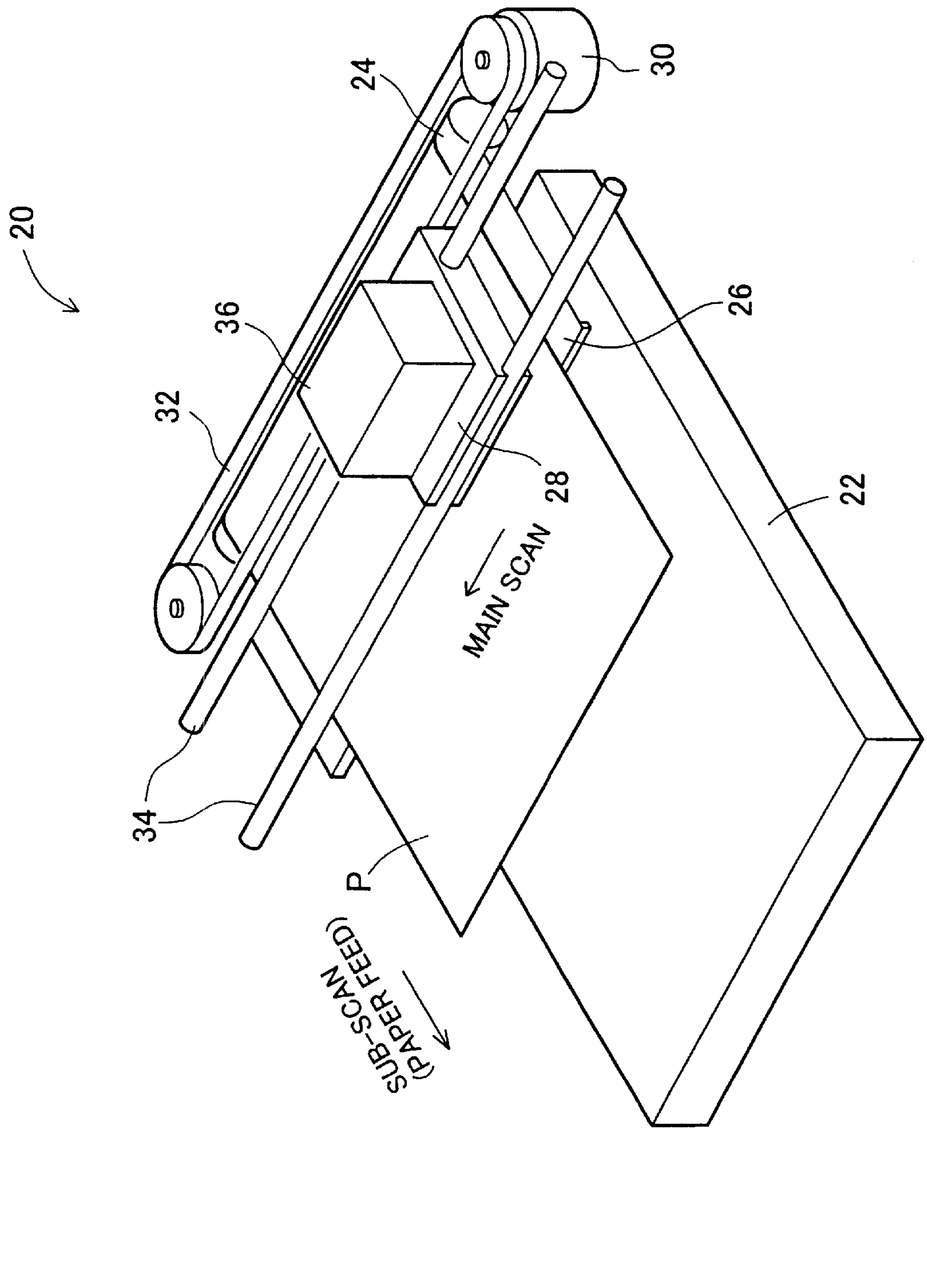


Fig. 1

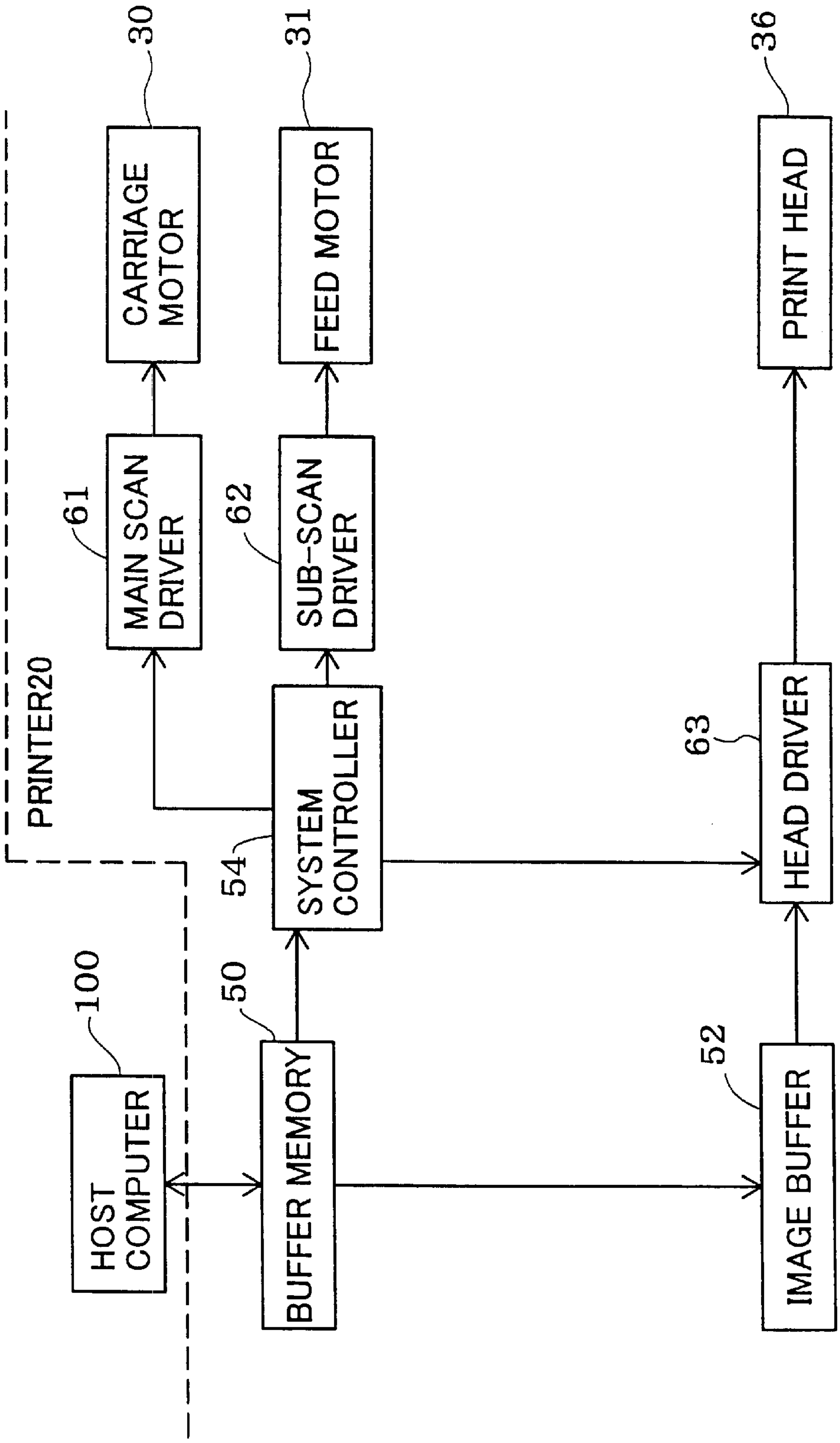

PRINTER20
CARRIAGE MOTOR
30
FEED MOTOR
31
PRINT HEAD
36
MAIN SCAN DRIVER
61
SUB-SCAN DRIVER
62
SYSTEM CONTROLLER
54
HEAD DRIVER
63
HOST COMPUTER
100
BUFFER MEMORY
50
IMAGE BUFFER
52

Fig. 2

Fig. 3

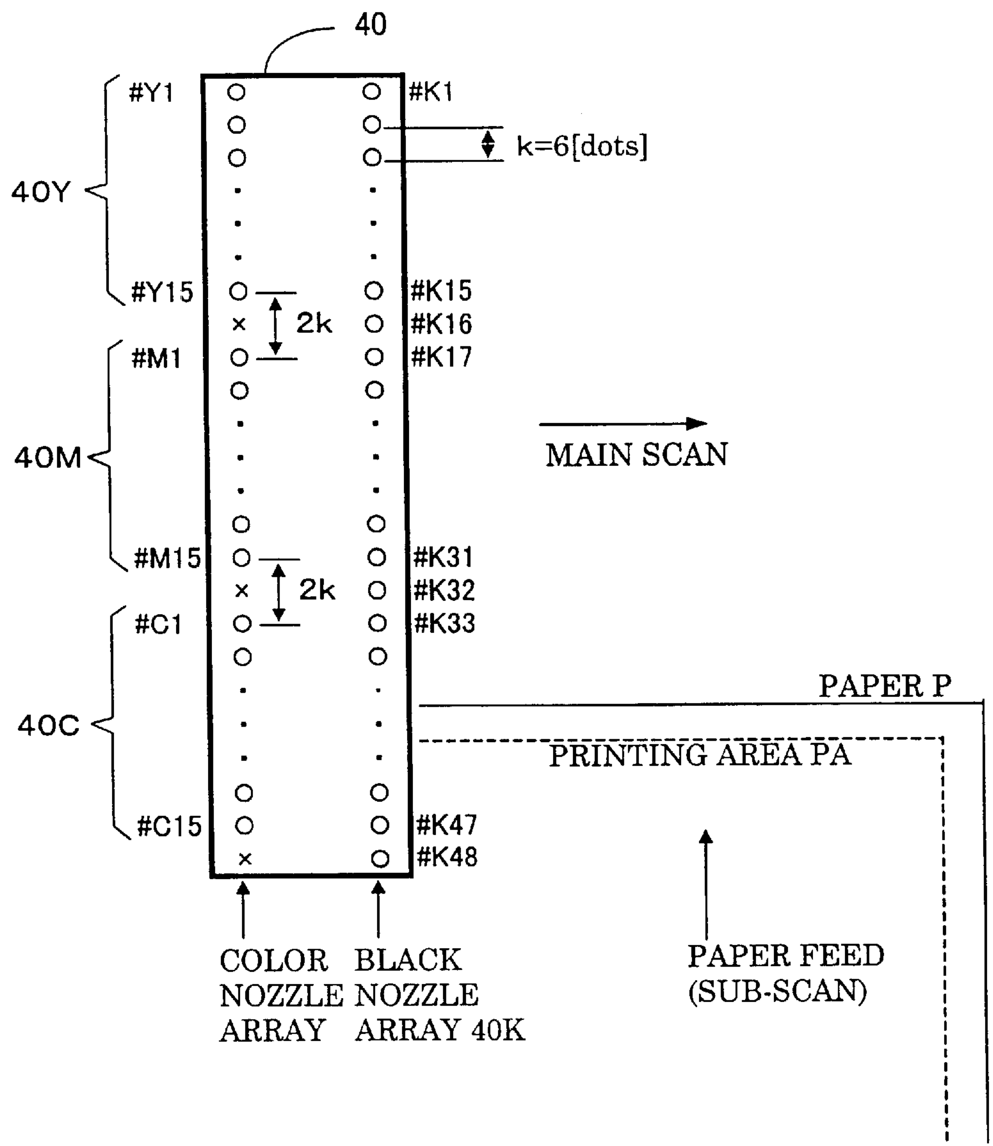

40
#Y1
#K1
k=6[dots]
40Y
#Y15
#K15
2k
#K16
#M1
#K17
MAIN SCAN
40M
#M15
#K31
2k
#K32
#C1
#K33
PAPER P
40C
PRINTING AREA PA
#C15
#K47
#K48
COLOR NOZZLE ARRAY
BLACK NOZZLE ARRAY 40K
PAPER FEED (SUB-SCAN)

Fig. 4

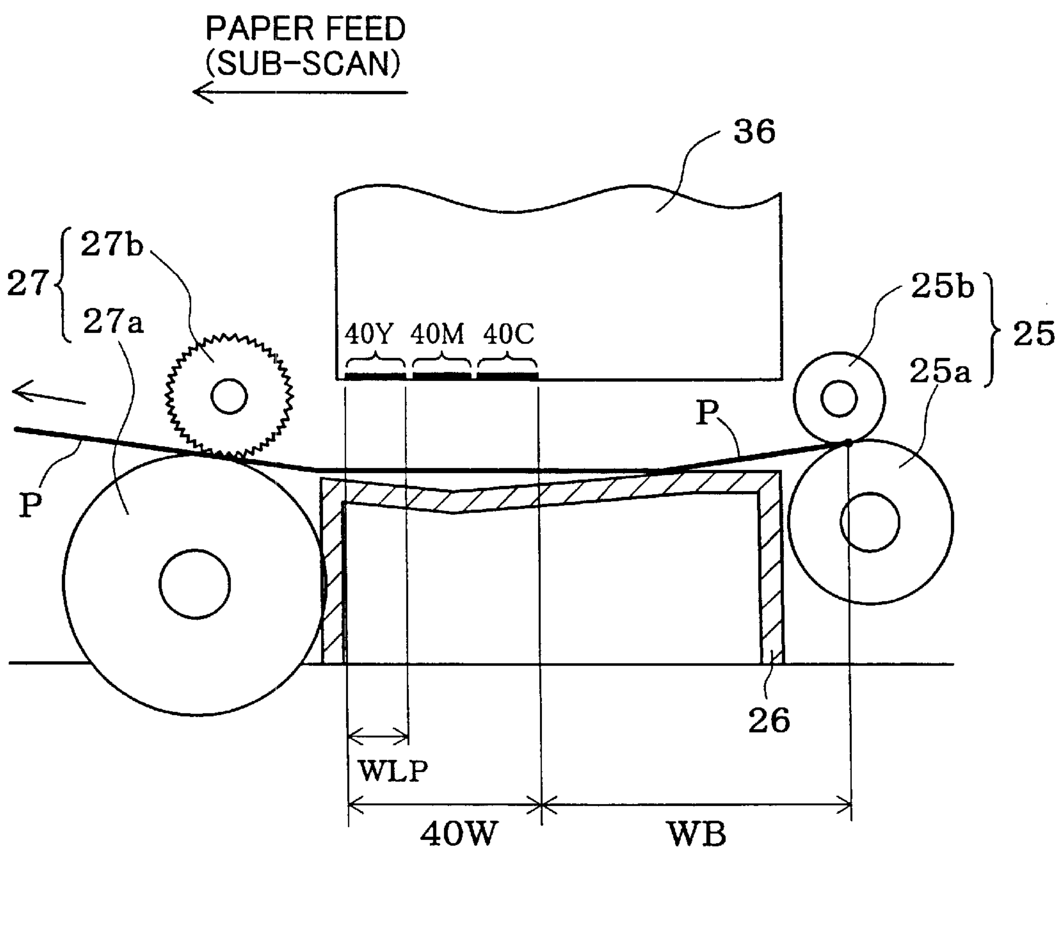

PAPER FEED
(SUB-SCAN)
36
27
27b
27a
40Y 40M 40C
25b
25
25a
P
P
26
WLP
40W
WB

Fig. 5 (A) CONCEPT OF SUB-SCAN FEED(s=1)

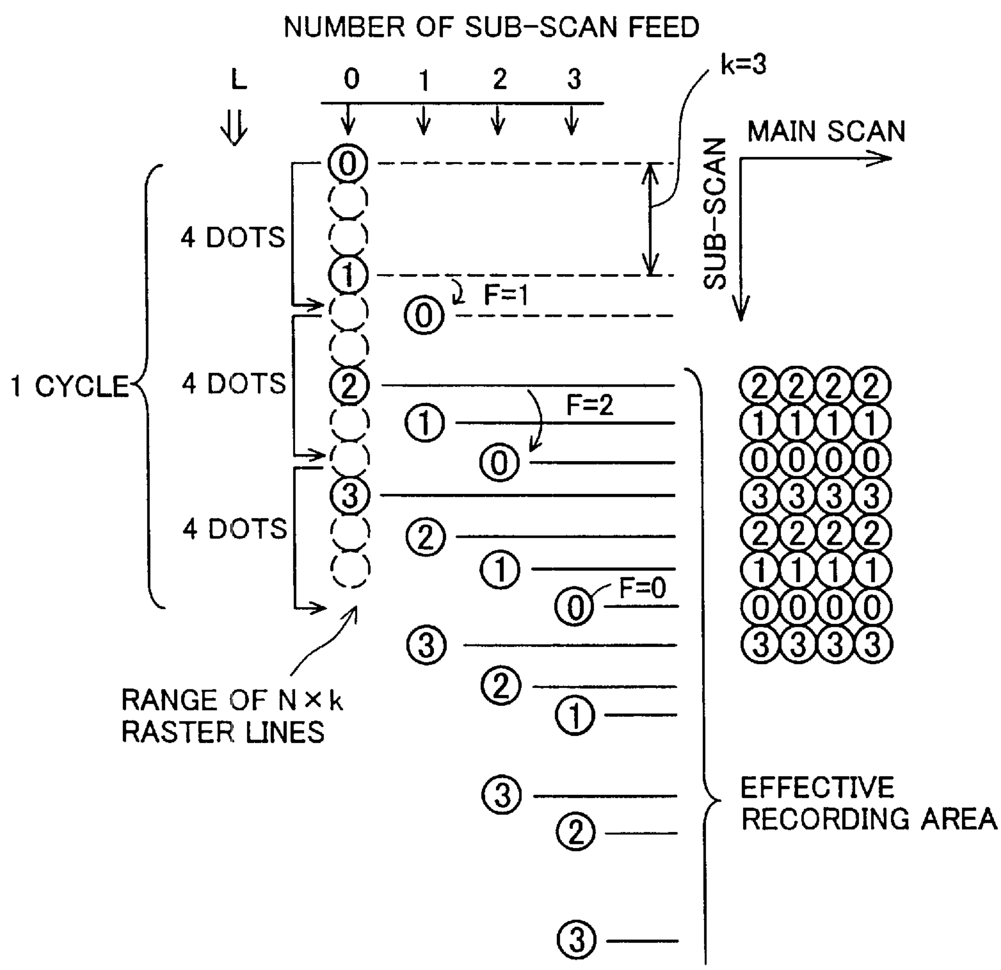


Fig. 5 (B) PARAMETERS

NOZZLE PITCH k : 3 [dot]
NUMBER OF USED NOZZLES N : 4
NUMBER OF SCAN REPEATS s : 1
NUMBER OF EFFECTIVE NOZZLES Neff : 4

NUMBER OF SUB-SCAN FEED	0	1	2	3
FEED AMOUNT L [dot]	0	4	4	4
ΣL	0	4	8	12
$F=(\Sigma L)\%k$	0	1	2	0

Fig. 6 (A) CONCEPT OF SUB-SCAN FEED(s=2)

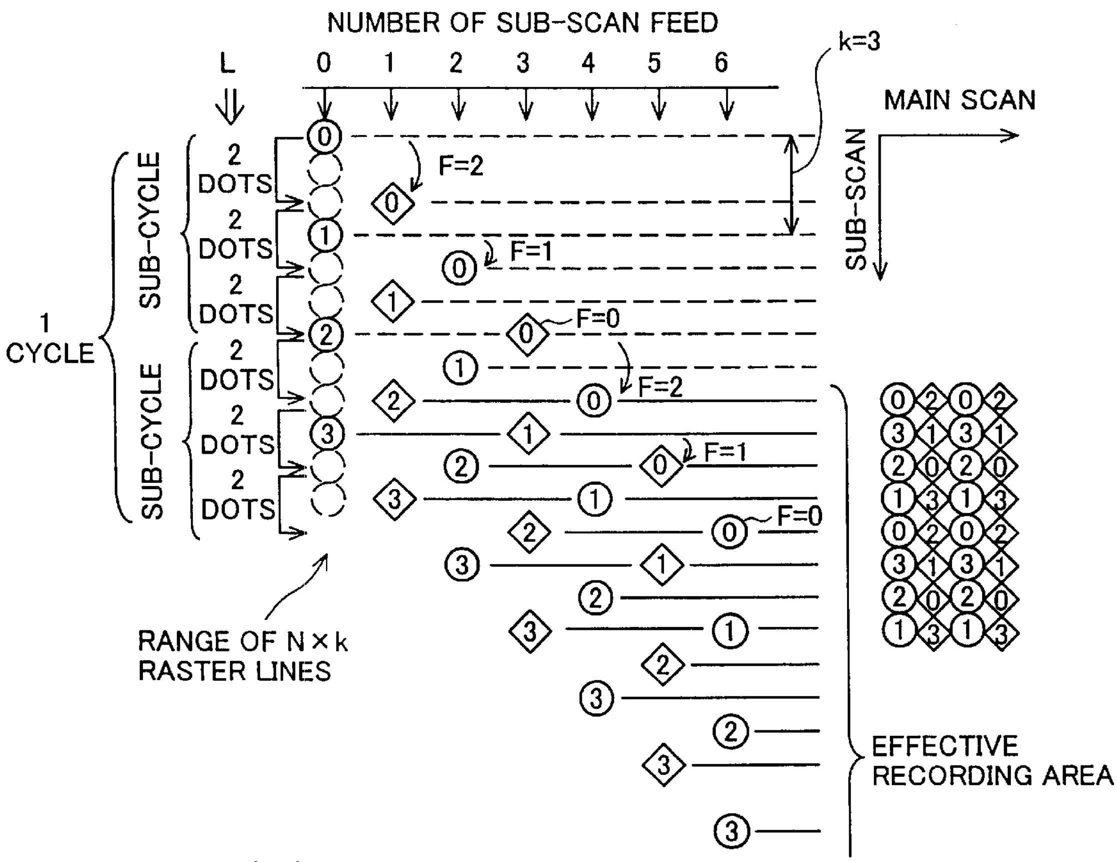


Fig. 6 (B) PARAMETERS

NOZZLE PITCH k : 3 [dot]
NUMBER OF USED NOZZLES N : 4
NUMBER OF SCAN REPEATS s : 2
NUMBER OF EFFECTIVE NOZZLES Neff : 2

NUMBER OF SUB-SCAN FEED	0	1	2	3	4	5	6
FEED AMOUNT L [dot]	0	2	2	2	2	2	2
ΣL	0	2	4	6	8	10	12
$F=(\Sigma L)\%k$	0	2	1	0	2	1	0

Fig. 7

SCAN PARAMETERS IN FIRST EMBODIMENT

Nozzle pitch : k = 6 [dots]
Number of scan repeats : s = 1
Number of working nozzles : N = 13
Number of effective nozzles : Neff = 13

PASS No.	1	2	3	4	5	6	7
SUB-SCAN No	0	1	2	3	4	5	6
FEED L [dots]	0	13	13	13	13	13	13
ΣL	0	13	26	39	52	65	78
$F=(\Sigma L)\%k$	0	1	2	3	4	5	0

Fig. 8

WORKING NOZZLES IN FIRST EMBODIMENT

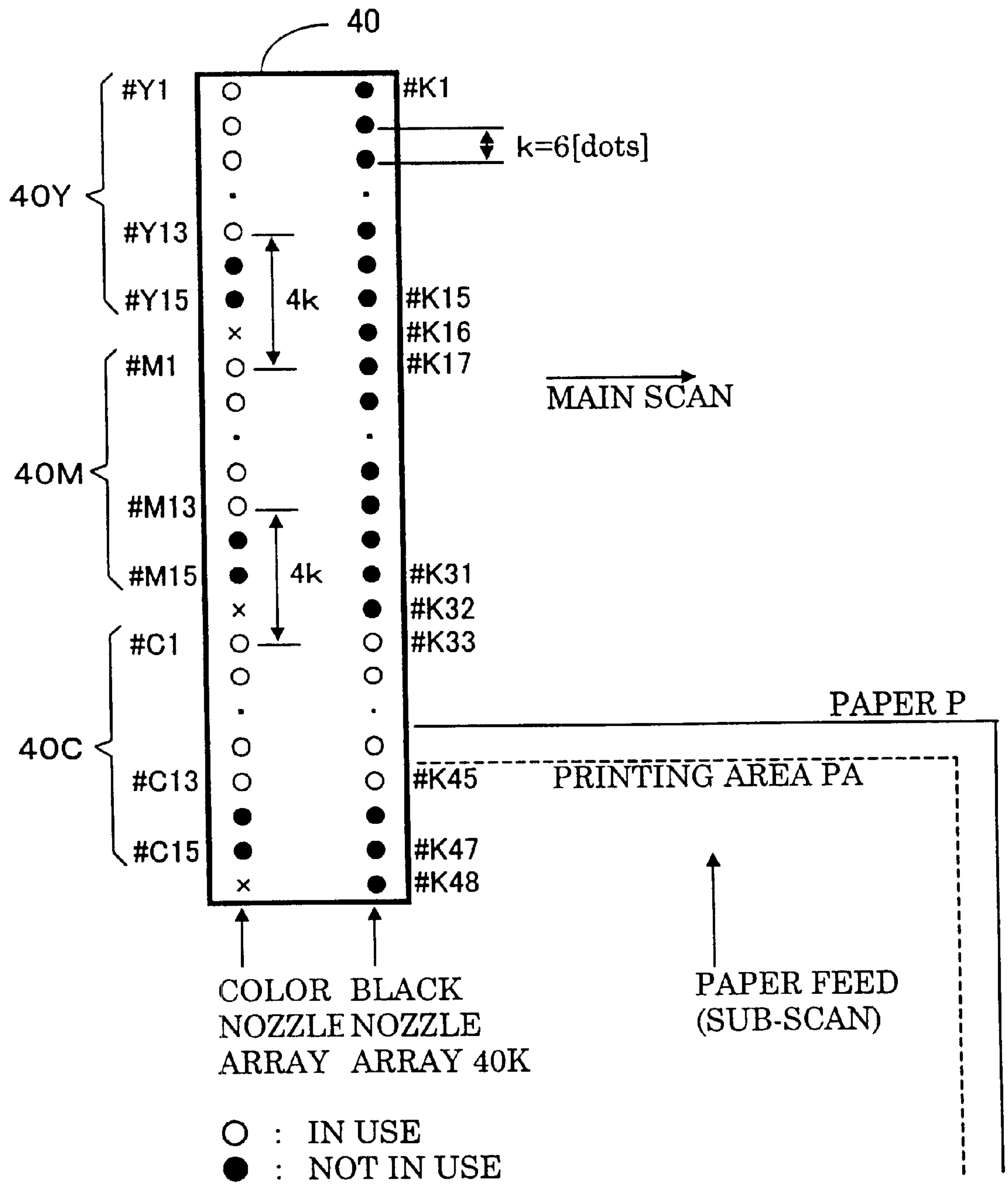


Fig. 9

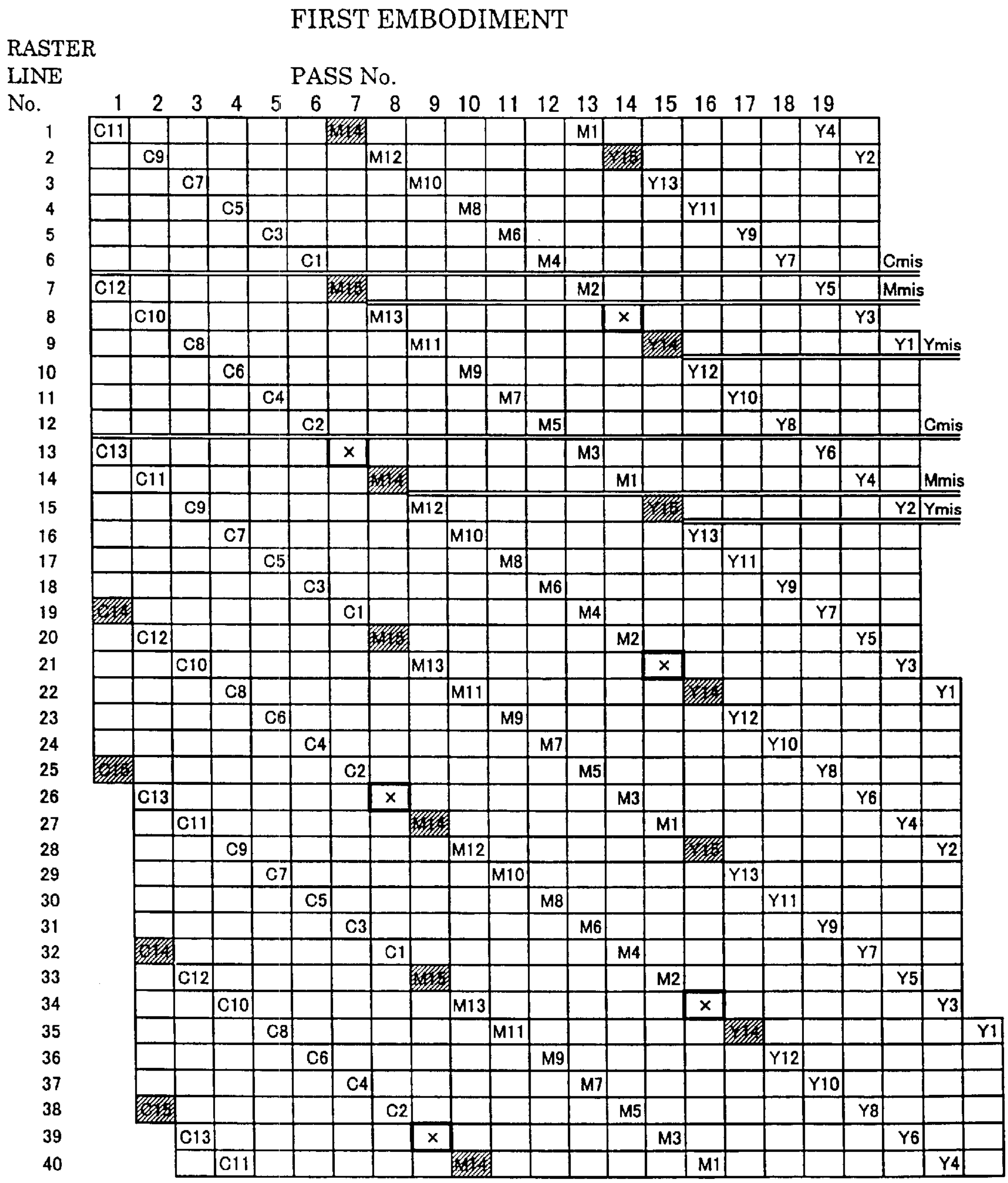


Fig. 10

WORKING NOZZLES IN FIRST COMPARATIVE EXAMPLE

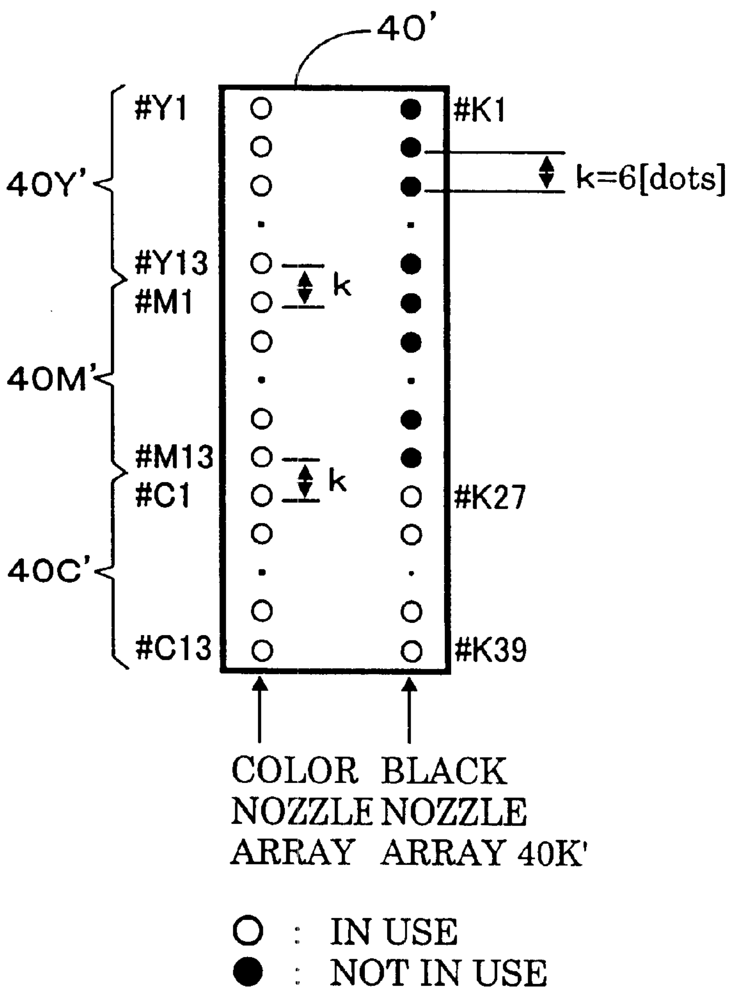


Fig. 11

FIRST COMPARATIVE EXAMPLE

RASTER LINE No. \ PASS No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		
1	C11						M11						Y11								
2		C9						M9						Y9							
3			C7						M7						Y7						
4				C5						M5						Y5					
5					C3						M3						Y3				
6						C1						M1						Y1			Cmis, Mmis, Ymis
7	C12						M12						Y12								
8		C10						M10						Y10							
9			C8						M8						Y8						
10				C6						M6						Y6					
11					C4						M4						Y4				
12						C2						M2						Y2			Cmis, Mmis, Ymis
13	C13						M13						Y13								
14		C11						M11						Y11							
15			C9						M9						Y9						
16				C7						M7						Y7					
17					C5						M5						Y5				
18						C3						M3						Y3			
19							C1						M1						Y1		
20		C12						M12						Y12							
21			C10						M10						Y10						
22				C8						M8						Y8					
23					C6						M6						Y6				
24						C4						M4						Y4			
25							C2						M2						Y2		
26		C13						M13						Y13							
27			C11						M11						Y11						
28				C9						M9						Y9					
29					C7						M7						Y7				
30						C5						M5						Y5			
31							C3						M3						Y3		
32								C1						M1						Y1	
33			C12						M12						Y12						
34				C10						M10						Y10					
35					C8						M8						Y8				
36						C6						M6						Y6			
37							C4						M4						Y4		
38								C2						M2						Y2	
39			C13						M13						Y13						
40				C11						M11						Y11					

Fig. 12

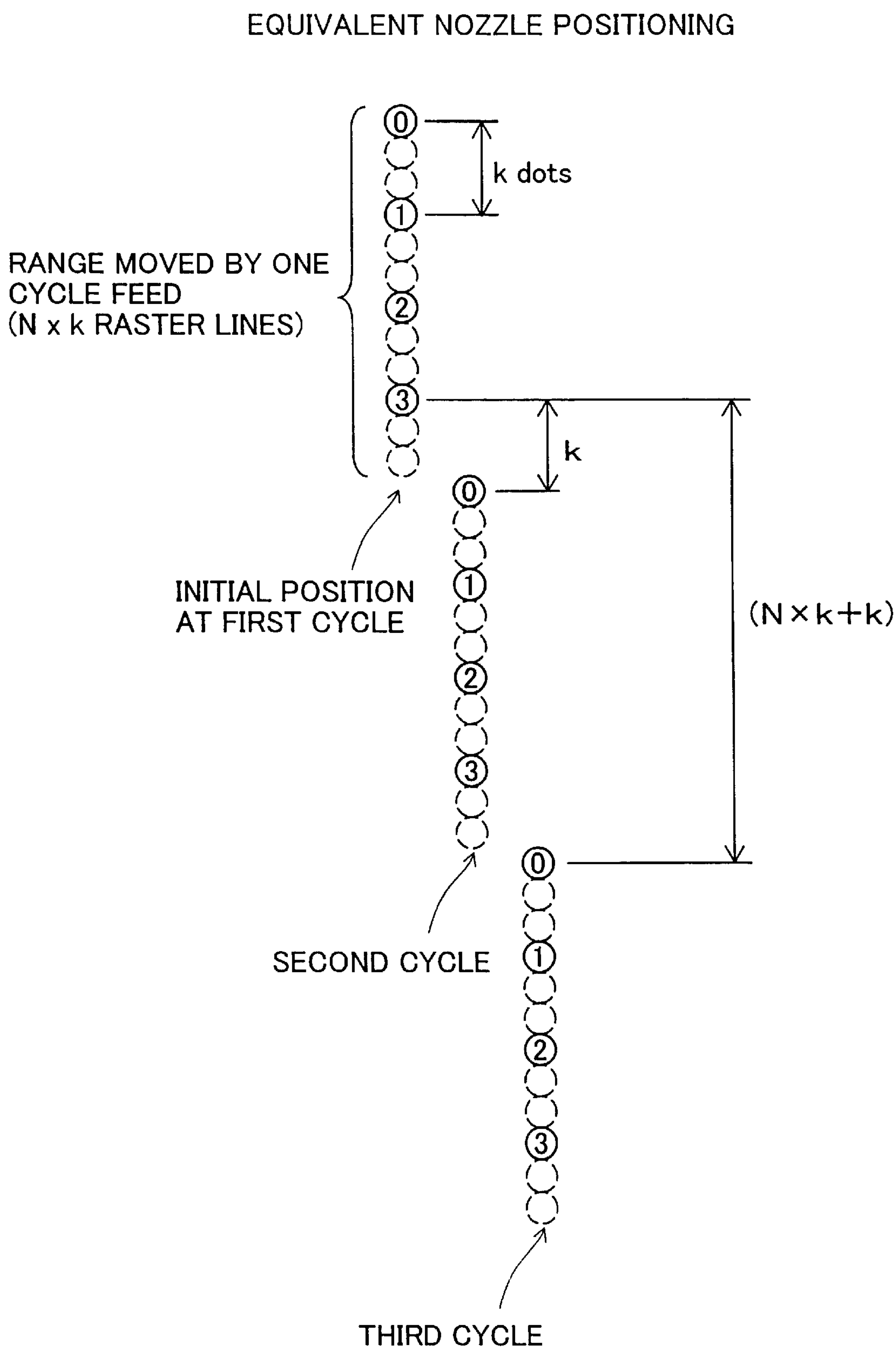

EQUIVALENT NOZZLE POSITIONING
0
1
2
3
k dots
RANGE MOVED BY ONE CYCLE FEED (N x k RASTER LINES)
k
(N×k+k)
INITIAL POSITION AT FIRST CYCLE
SECOND CYCLE
THIRD CYCLE

Fig. 13

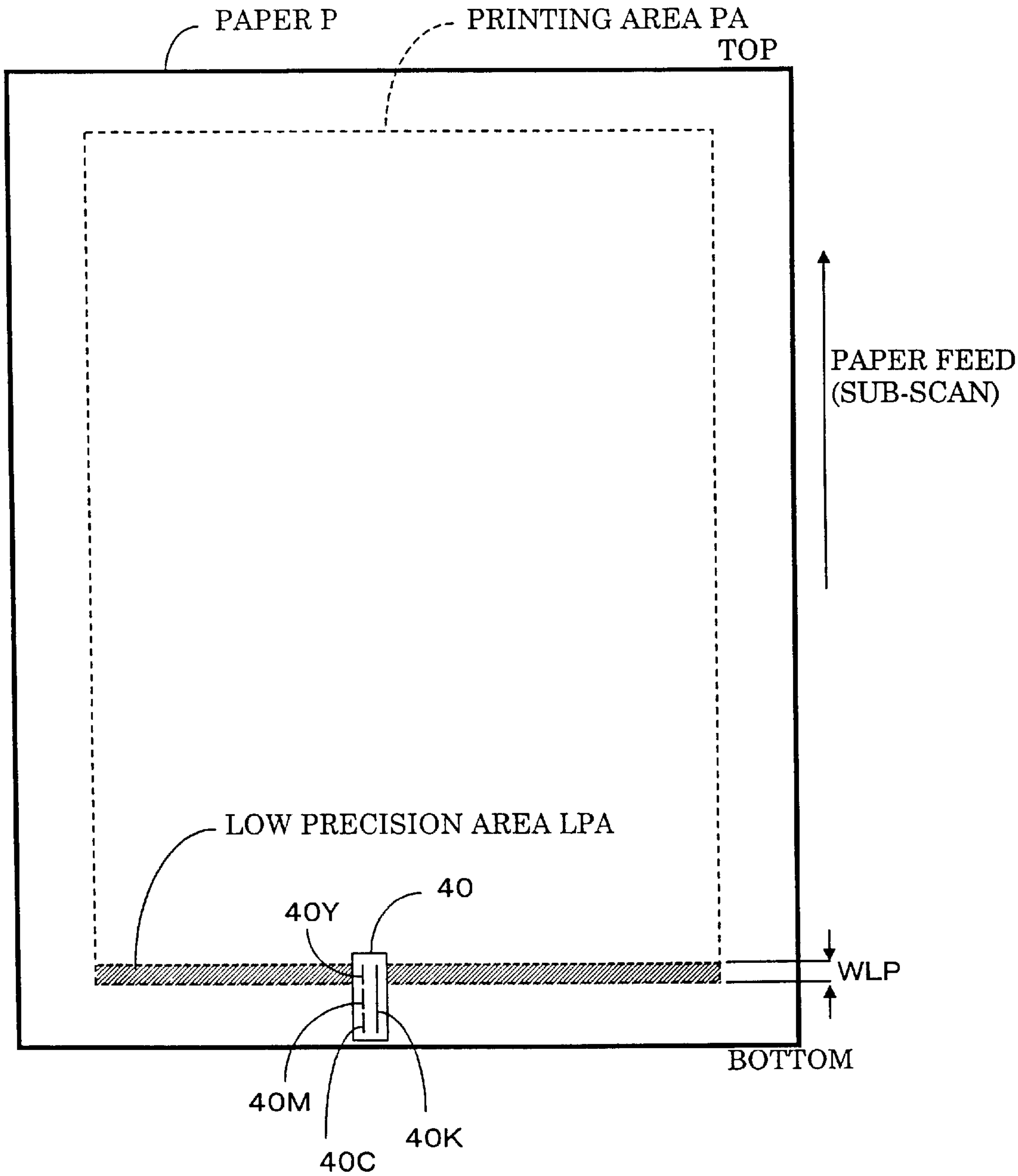

PAPER P
PRINTING AREA PA
TOP
PAPER FEED
(SUB-SCAN)
LOW PRECISION AREA LPA
40
40Y
WLP
BOTTOM
40M
40C
40K

Fig. 14

SCAN PARAMETERS IN SECOND EMBODIMENT

Nozzle pitch : k = 6 [dots]
Number of scan repeats : s = 1
Number of working nozzles : N = 15
Number of effective nozzles : Neff = 15

PASS No.	1	2	3	4	5	6	7
SUB-SCAN No	0	1	2	3	4	5	6
FEED L [dots]	0	14	15	16	16	15	14
ΣL	0	14	29	45	61	76	90
F=(ΣL)%k	0	2	5	3	1	4	0

Fig. 15

WORKING NOZZLES IN SECOND EMBODIMENT

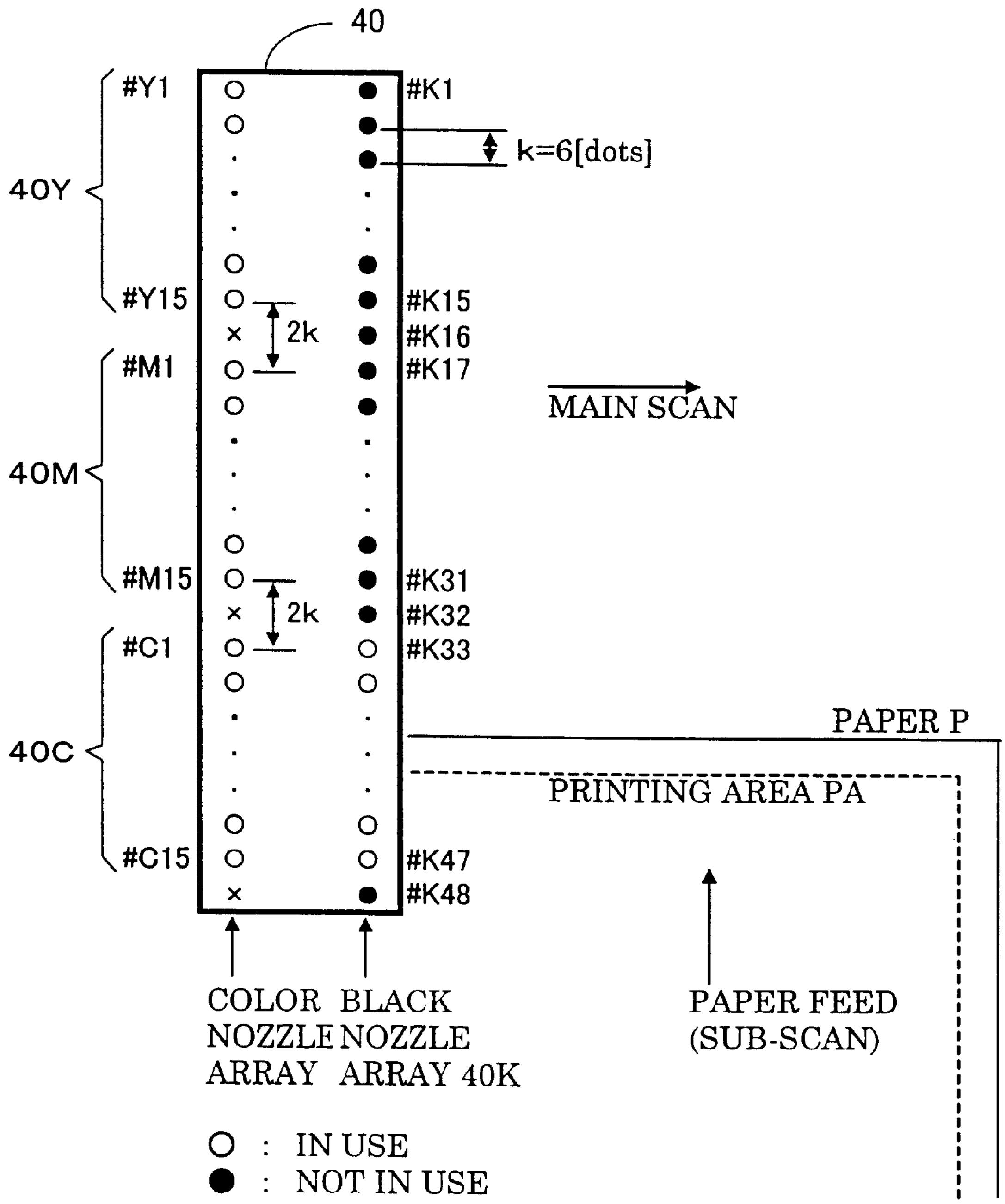


Fig. 16

SECOND EMBODIMENT

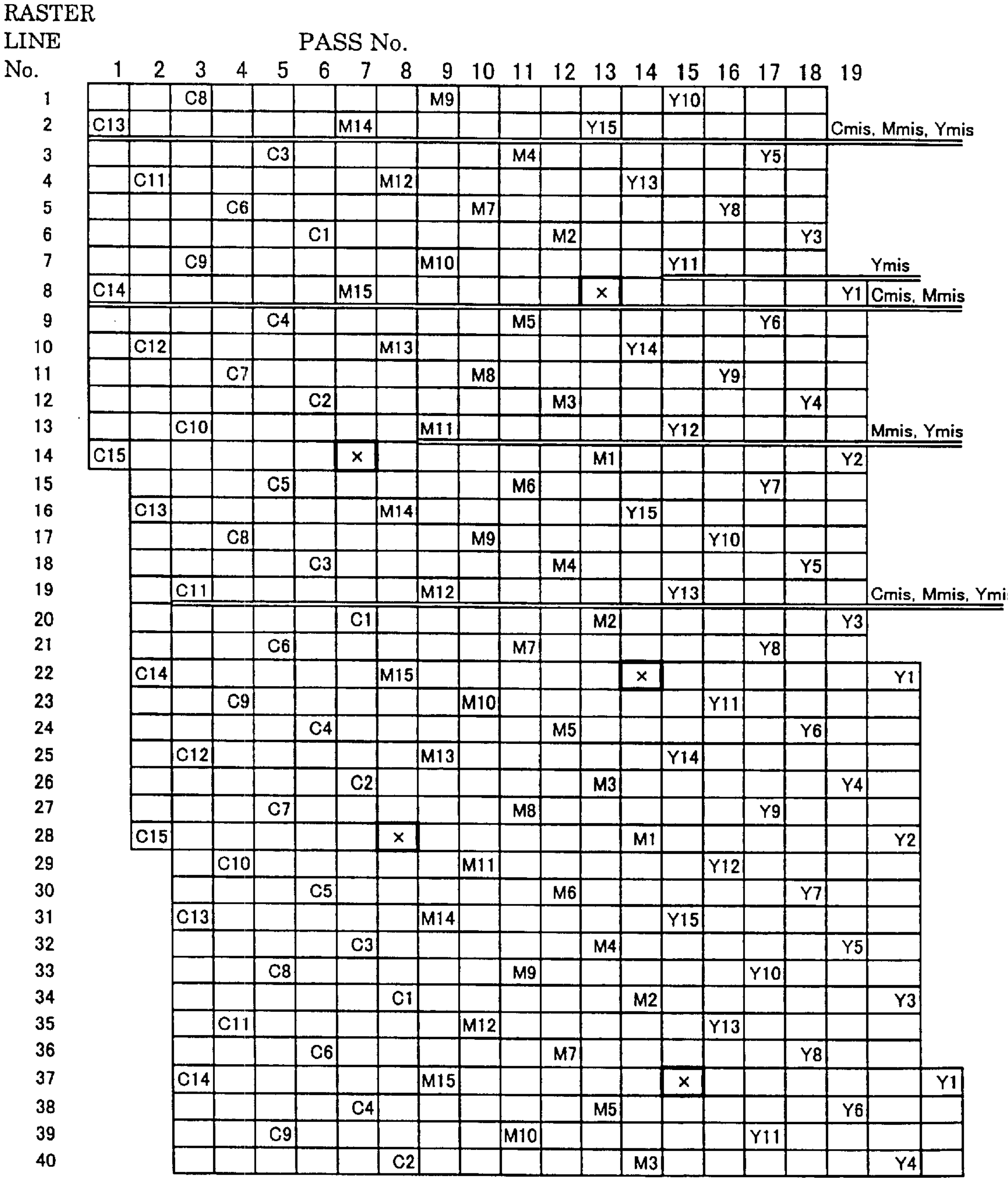


Fig. 17

WORKING NOZZLES IN SECOND COMPARATIVE EXAMPLE

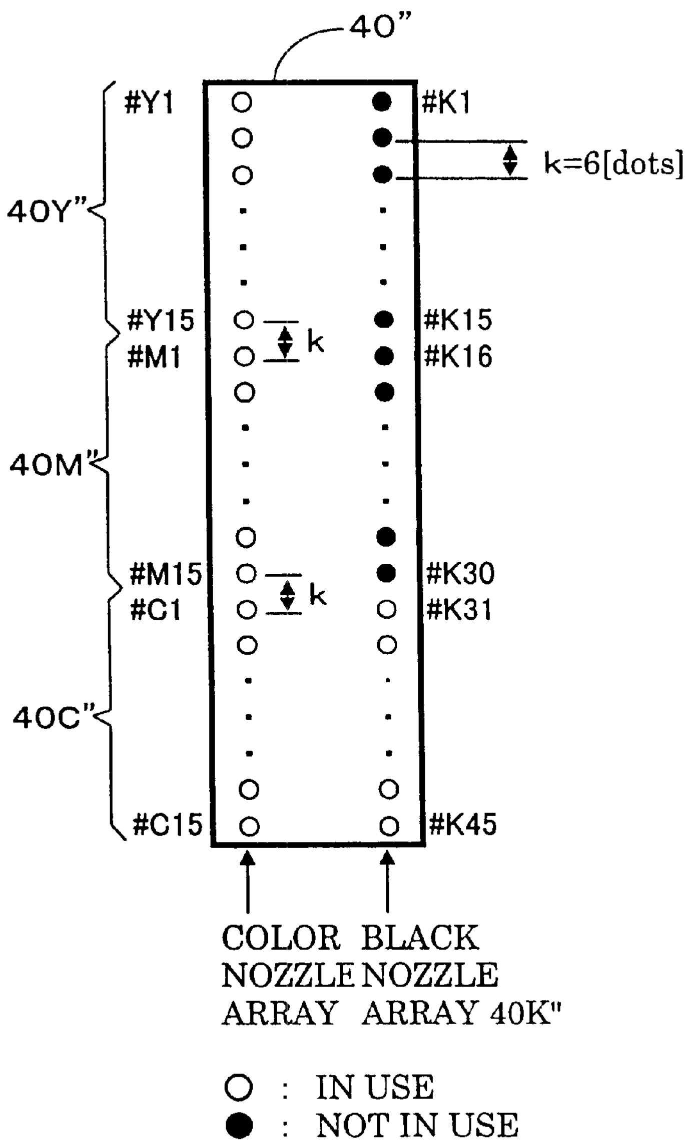


Fig. 18

SECOND COMPARATIVE EXAMPLE

RASTER LINE No. \ PASS No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		
1			C8						M8						Y8						
2	C13						M13						Y13								Cmis, Mmis, Ymis
3					C3						M3						Y3				
4		C11						M11						Y11							
5				C6						M6						Y6					
6						C1						M1						Y1			
7			C9						M9						Y9						
8	C14						M14						Y14								Cmis, Mmis, Ymis
9					C4						M4						Y4				
10		C12						M12						Y12							
11				C7						M7						Y7					
12						C2						M2						Y2			
13			C10						M10						Y10						
14	C15						M15						Y15								Cmis, Mmis, Ymis
15					C5						M5						Y5				
16		C13						M13						Y13							
17				C8						M8						Y8					
18						C3						M3						Y3			
19			C11						M11						Y11						
20							C1						M1						Y1		
21					C6						M6						Y6				
22		C14						M14						Y14							
23				C9						M9						Y9					
24						C4						M4						Y4			
25			C12						M12						Y12						
26							C2						M2						Y2		
27					C7						M7						Y7				
28		C15						M15						Y15							
29				C10						M10						Y10					
30						C5						M5						Y5			
31			C13						M13						Y13						
32							C3						M3						Y3		
33					C8						M8						Y8				
34								C1						M1						Y1	
35				C11						M11						Y11					
36						C6						M6						Y6			
37			C14						M14						Y14						
38							C4						M4						Y4		
39					C9						M9						Y9				
40								C2						M2						Y2	

Fig. 19

FIRST ACTUATOR VARIATION

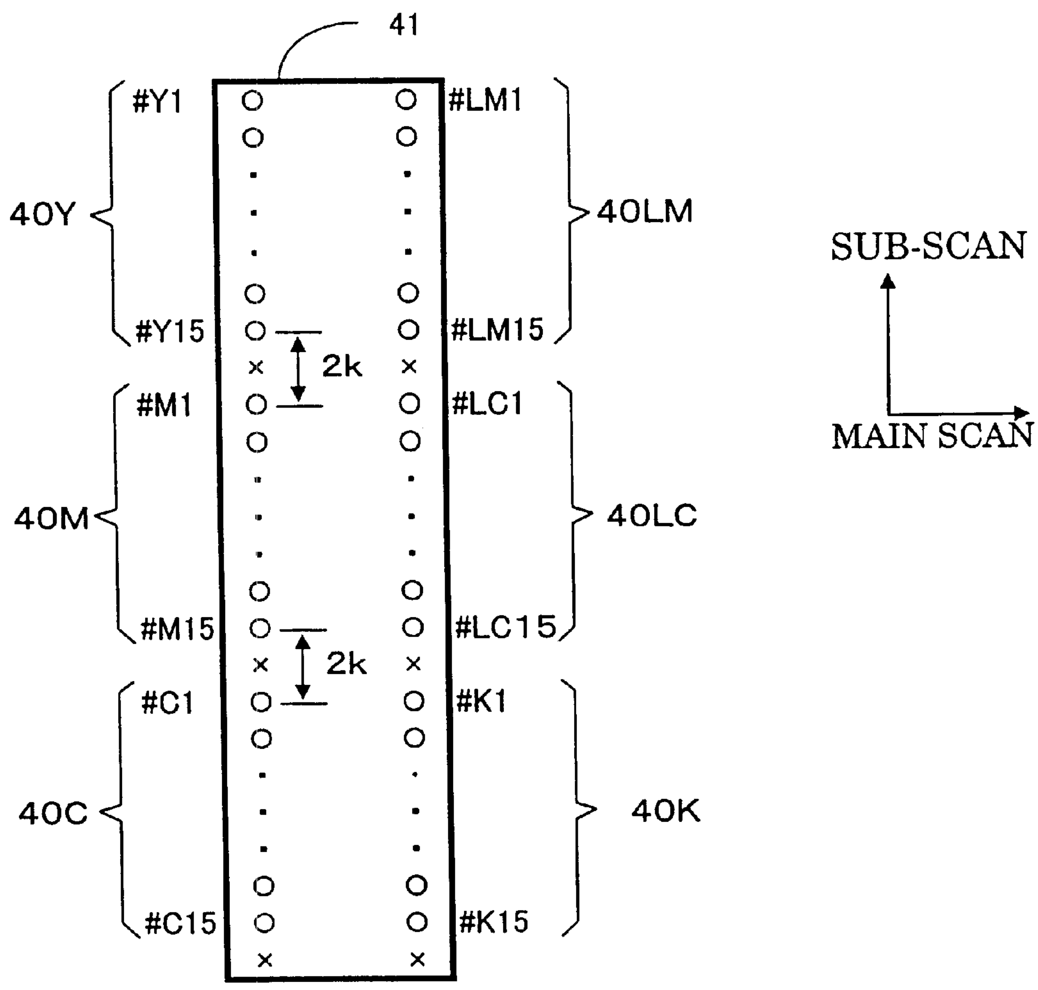


Fig. 20

SECOND ACTUATOR VARIATION

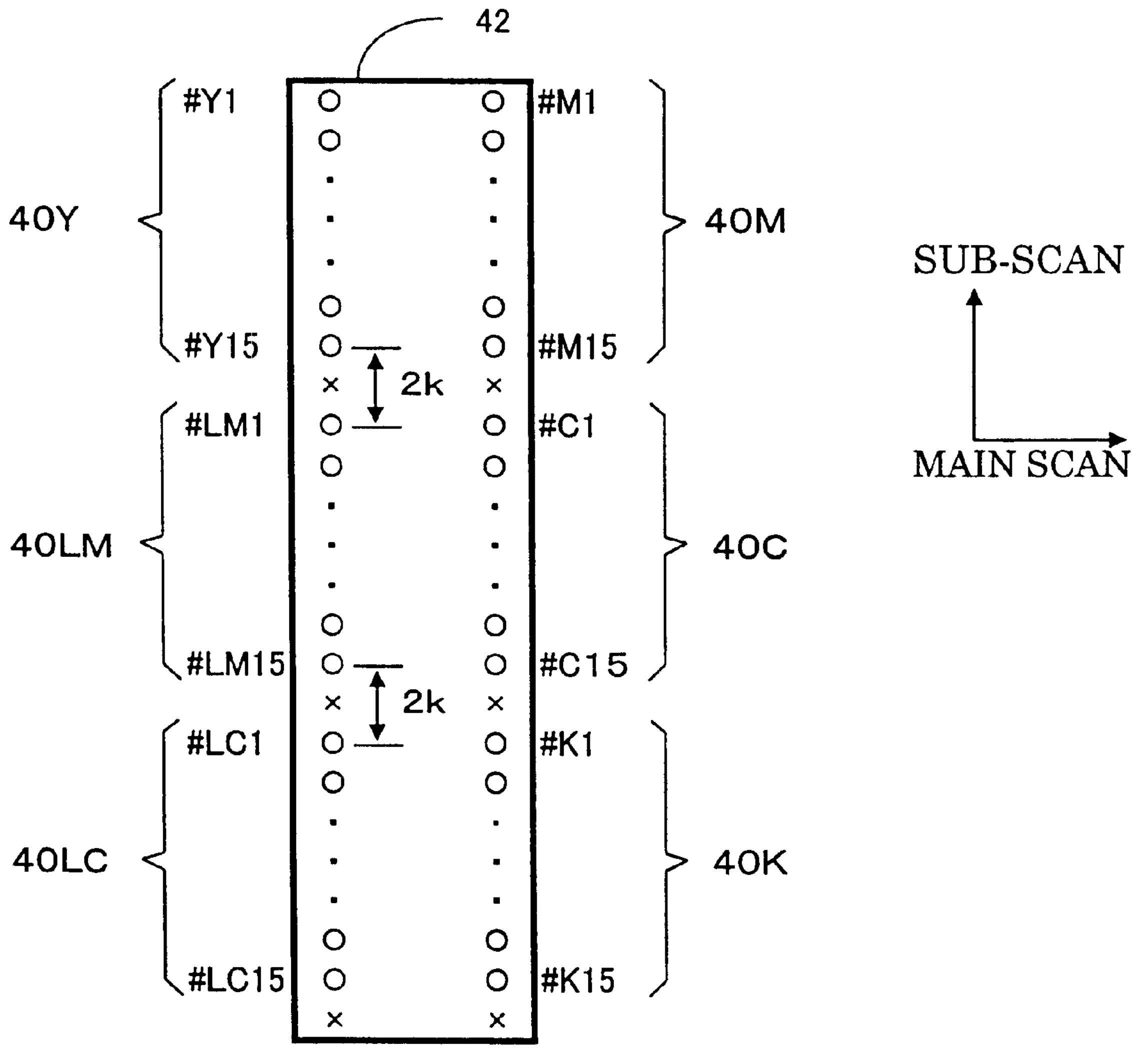


Fig. 21

THIRD ACTUATOR VARIATION

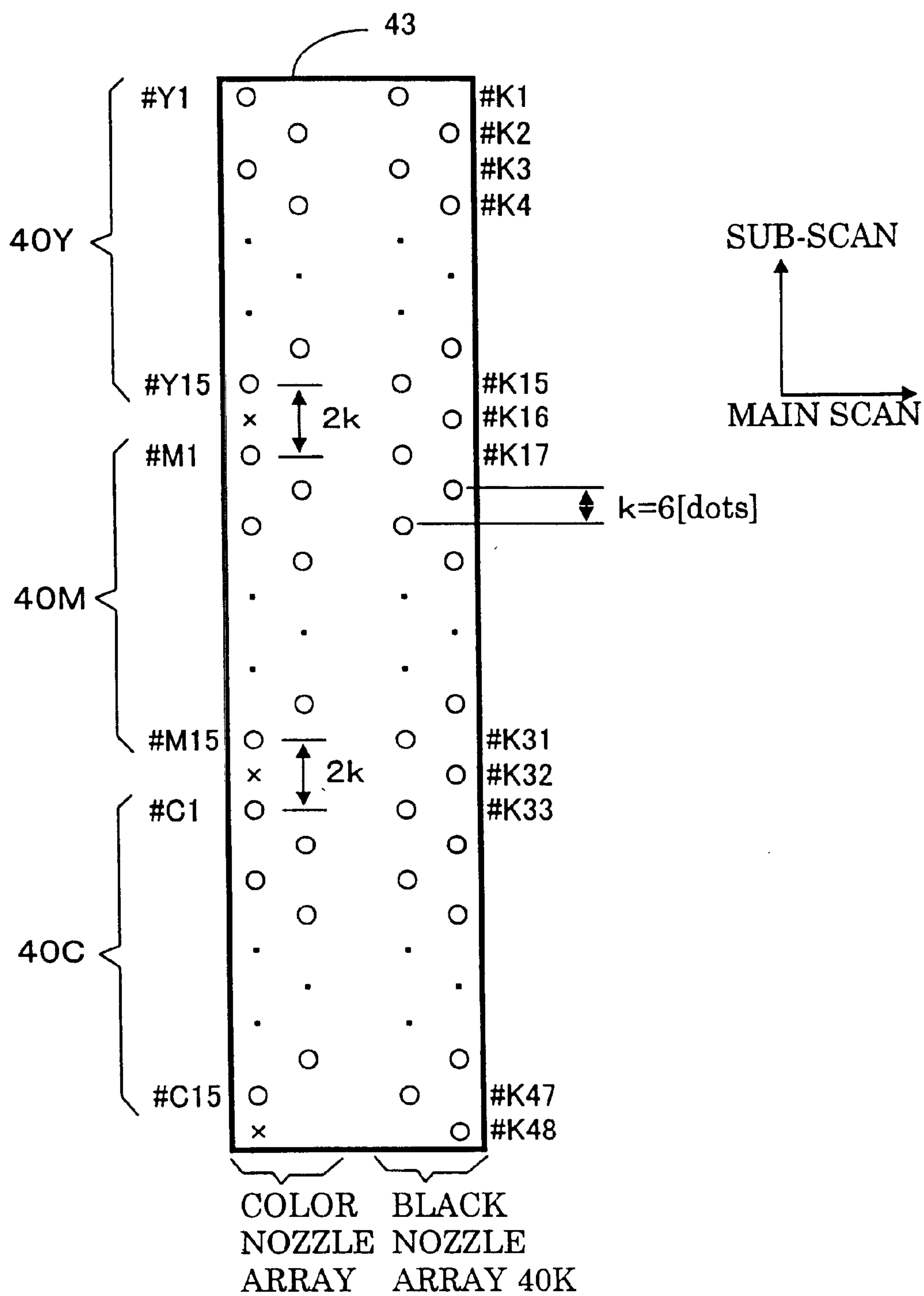


Fig. 22

FOURTH ACTUATOR VARIATION

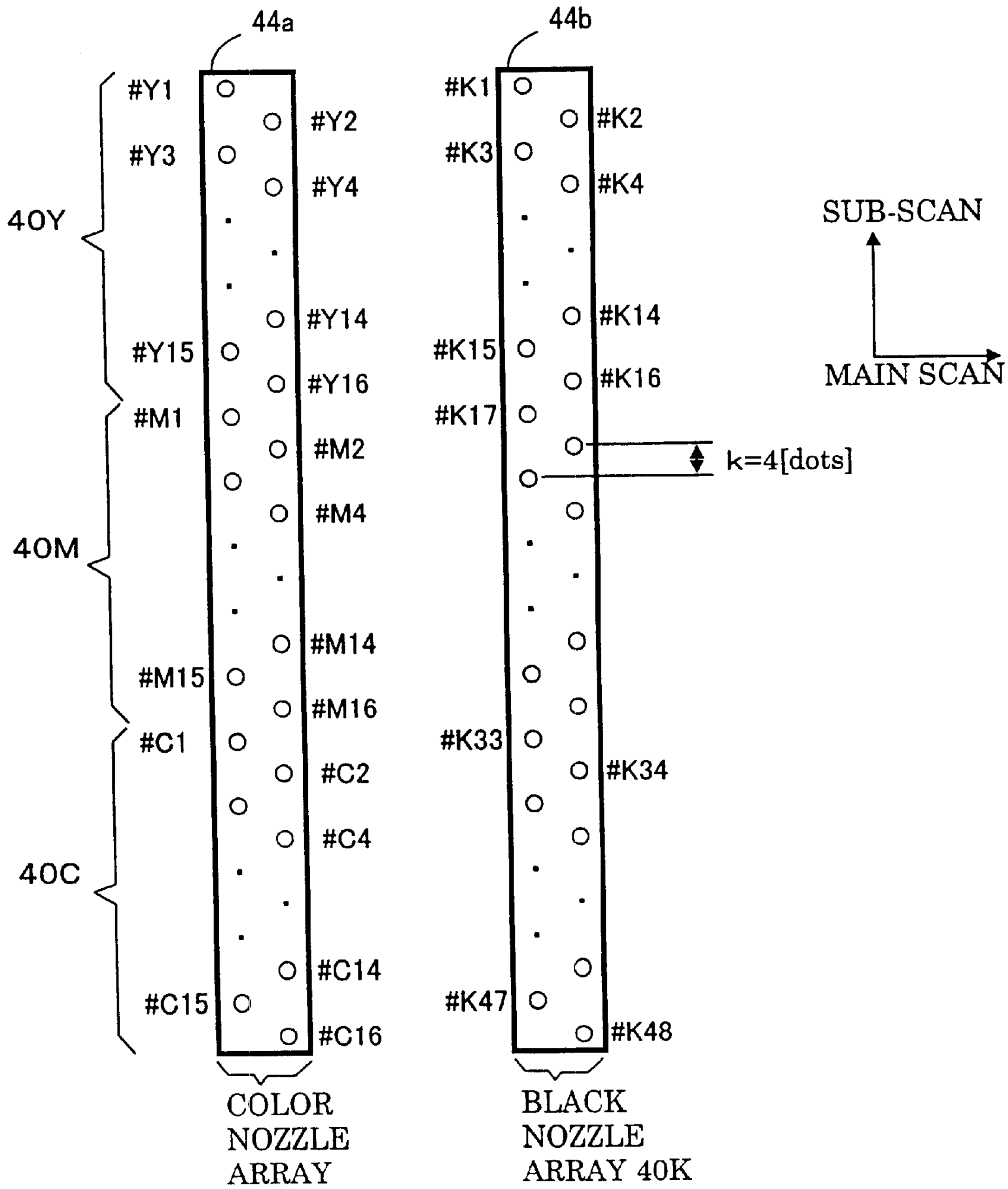


Fig. 23

FIFTH ACTUATOR VARIATION

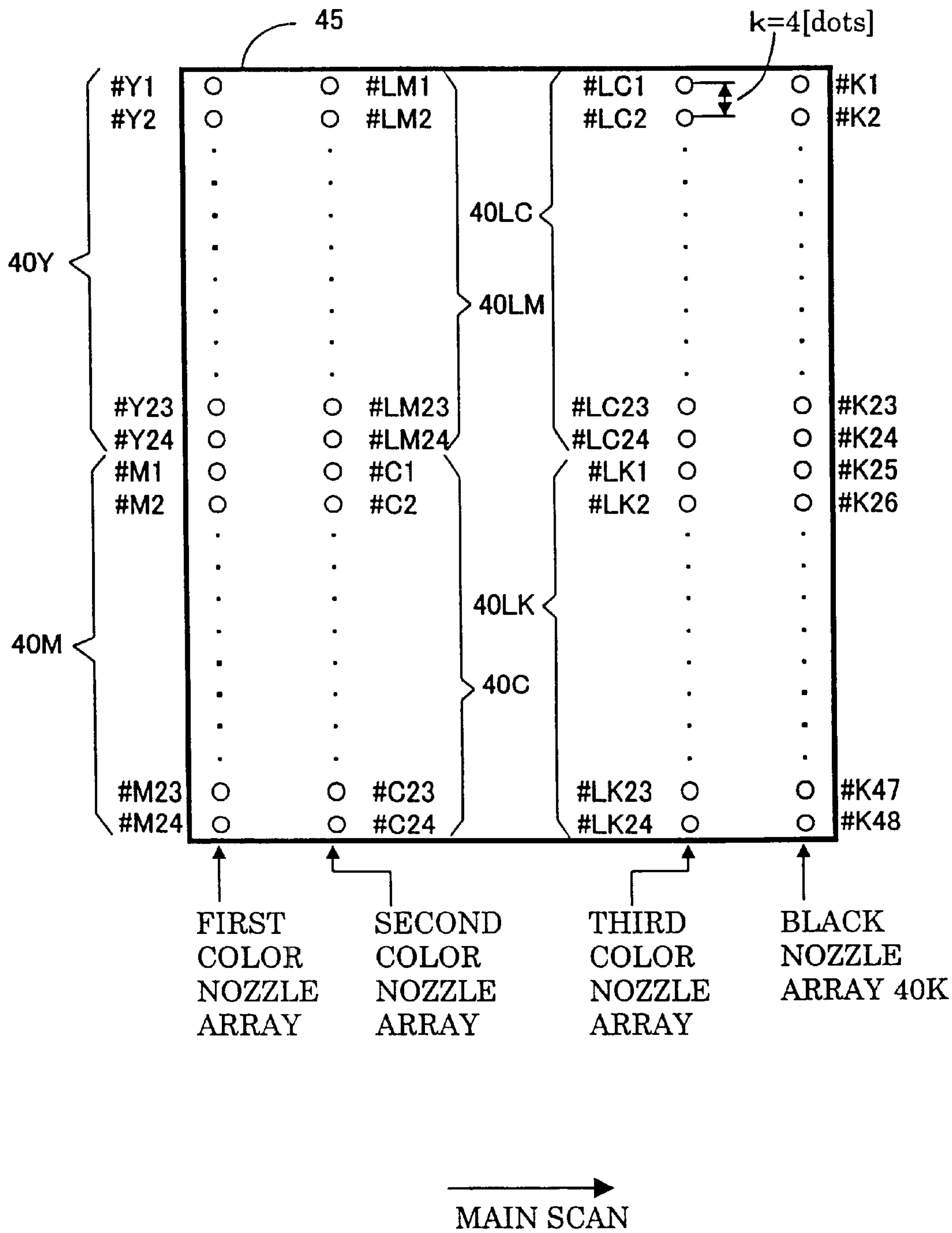


Fig. 24

SIXTH ACTUATOR VARIATION

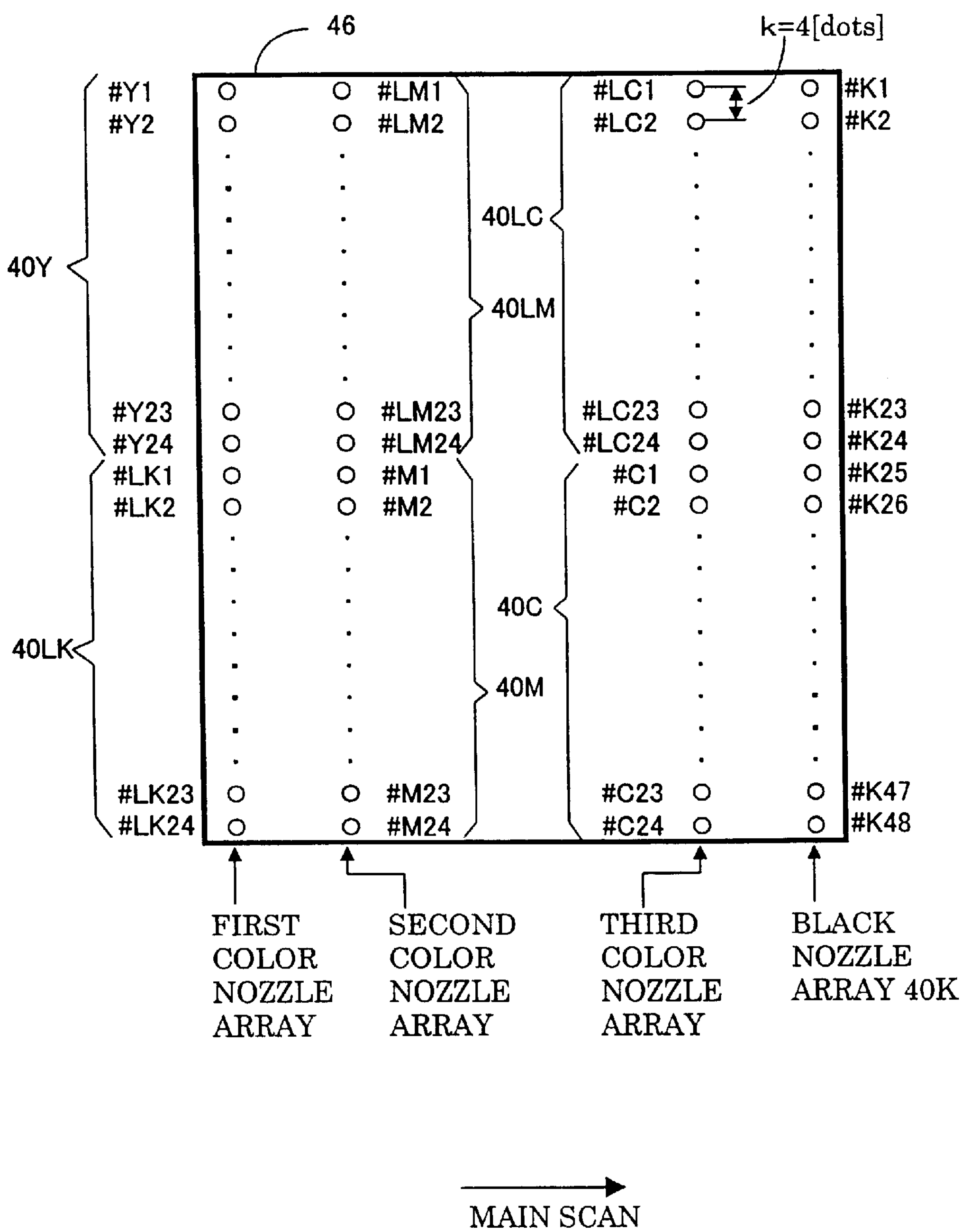


Fig. 25

SEVENTH ACTUATOR VARIATION

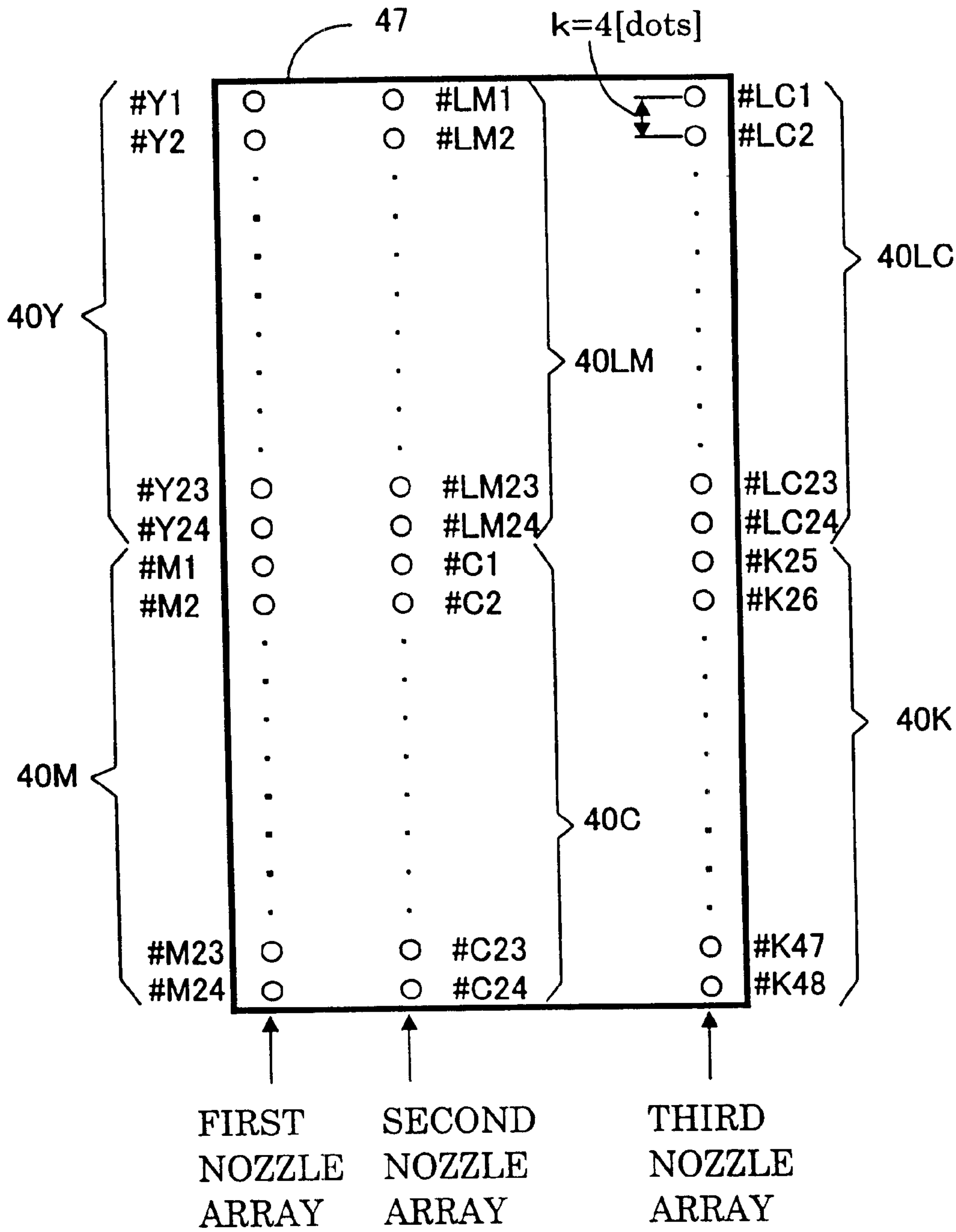


Fig. 26

EIGHTH ACTUATOR VARIATION

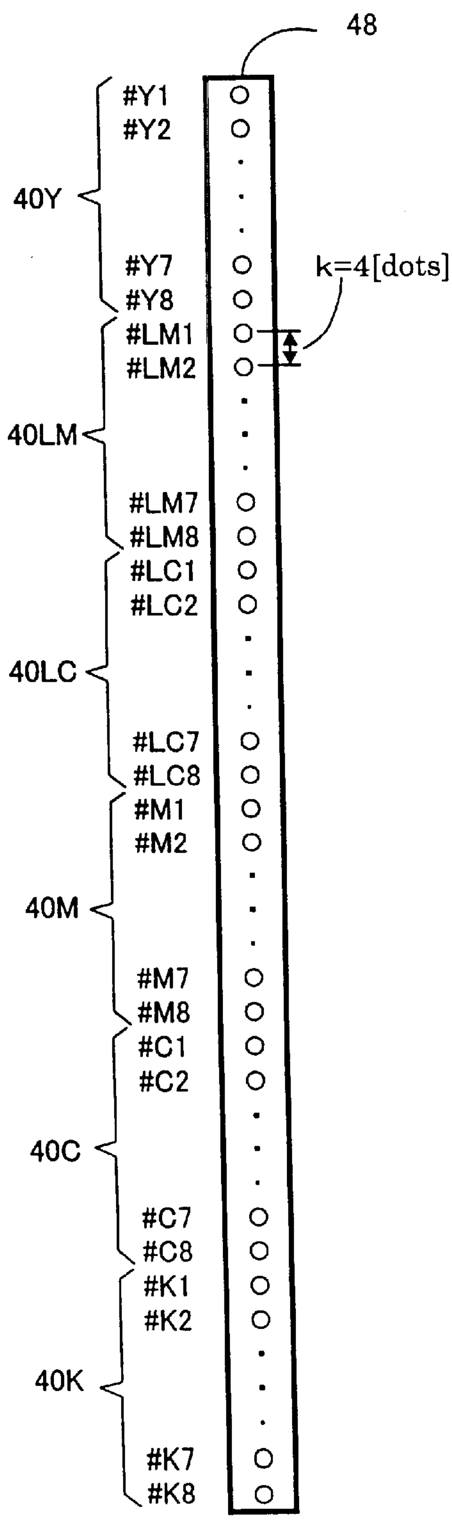


Fig. 27

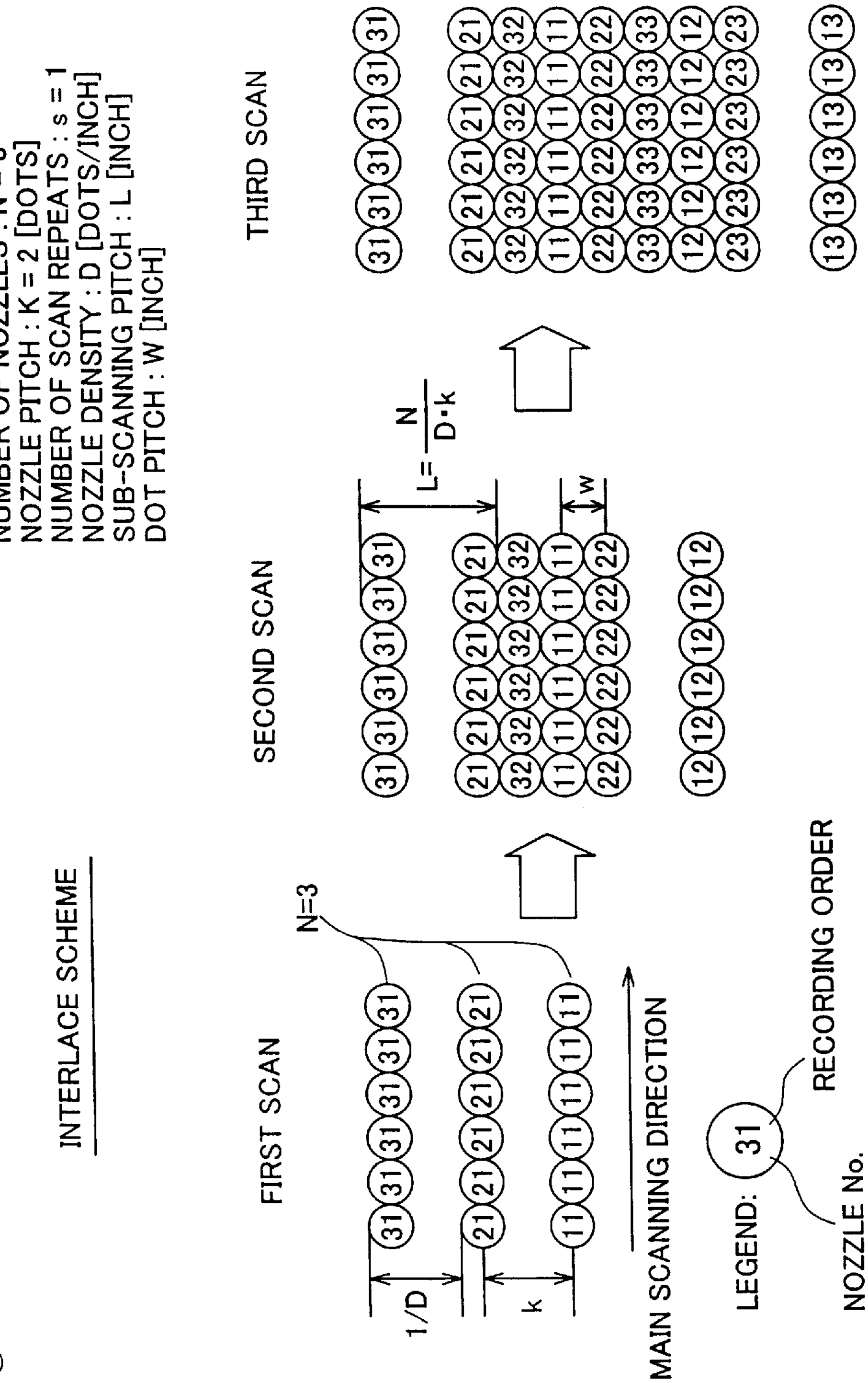
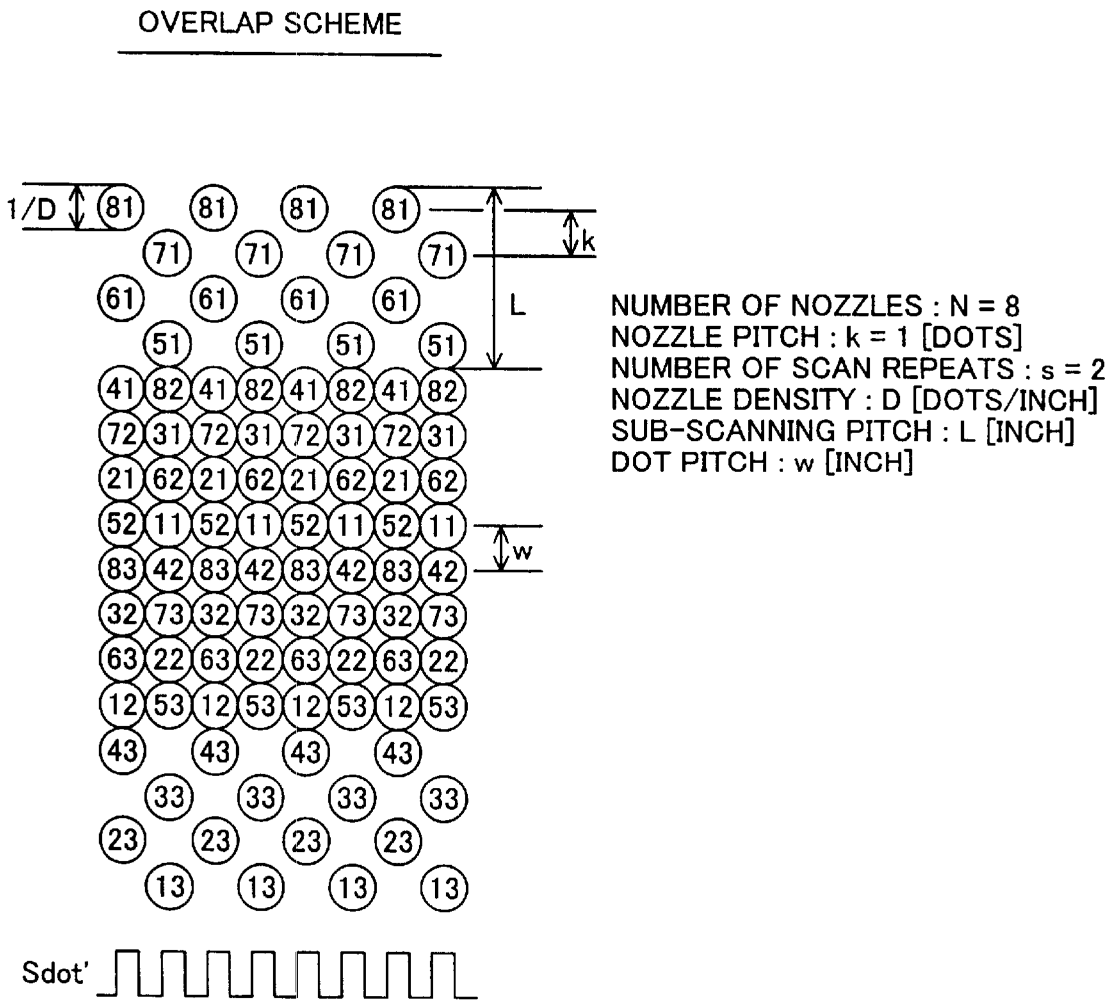

INTERLACE SCHEME
NUMBER OF NOZZLES : N = 3
NOZZLE PITCH : K = 2 [DOTS]
NUMBER OF SCAN REPEATS : s = 1
NOZZLE DENSITY : D [DOTS/INCH]
SUB-SCANNING PITCH : L [INCH]
DOT PITCH : W [INCH]
FIRST SCAN
SECOND SCAN
THIRD SCAN
N=3
1/D
k
L= N/D·k
w
MAIN SCANNING DIRECTION
LEGEND:
RECORDING ORDER
NOZZLE No.

Fig. 28


OVERLAP SCHEME
1/D
81 81 81 81
71 71 71 71
61 61 61 61
51 51 51 51
41 82 41 82 41 82 41 82
72 31 72 31 72 31 72 31
21 62 21 62 21 62 21 62
52 11 52 11 52 11 52 11
83 42 83 42 83 42 83 42
32 73 32 73 32 73 32 73
63 22 63 22 63 22 63 22
12 53 12 53 12 53 12 53
43 43 43 43
33 33 33 33
23 23 23 23
13 13 13 13
k
L
w
Sdot'
NUMBER OF NOZZLES : N = 8
NOZZLE PITCH : k = 1 [DOTS]
NUMBER OF SCAN REPEATS : s = 2
NOZZLE DENSITY : D [DOTS/INCH]
SUB-SCANNING PITCH : L [INCH]
DOT PITCH : w [INCH]

COLOR PRINTING USING A VERTICAL NOZZLE ARRAY HEAD

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a color printing apparatus that uses a print head for forming dots of a plurality of colors.

2. Description of the Related Art

Serial scan-type printers and drum scan-type printers are dot recording devices which record dots with a print head while carrying out scans both in a main scanning direction and a sub-scanning direction. There is a technique called "interlace scheme", which is taught by U.S. Pat. No. 4,198,642 and Japanese Patent Laid-Open Gazette No. 53-2040, for improving the image quality of printers of this type, especially ink jet printers.

FIG. **27** is a diagram for explaining an example of the interlace scheme. In this specification, the following parameters are used to define a printing scheme.

N: Number of nozzles;

k: Nozzle pitch [dots];

s: Number of scan repeats;

D: Nozzle density [nozzles/inch];

L: Sub-scanning amount [dots] or [inch];

w: Dot pitch [inch].

The number of nozzles N is the number of nozzles actually used to form dots. In the example of FIG. **18**, N=3. The nozzle pitch k is the interval between the centers of the recording head nozzles expressed in units of the recorded image pitch (dot pitch w). In the example of FIG. **27**, k=2. The number of scan repeats is the number of main scans in which all dot positions on a main scanning line are serviced. In the example of FIG. **27**, s=1, i.e., all dot positions on a main scanning line are serviced in a single main scan. When s is 2 or greater, the dots are formed intermittently in the main scanning direction. This will be explained in detail later. The nozzle density D (nozzle/inch) is the number of nozzles per inch in the nozzle array of the print head. The sub-scanning amount L (inch) is the distance moved in 1 sub-scan. The dot pitch w (inch) is the pitch of the dots in the recorded image. In general, it holds that $w=1/(D\cdot k)$, $k=1/(D\cdot w)$.

The circles containing two-digit numerals in FIG. **27** indicate dot recording positions. As indicated in the legend, the numeral on the left in each circle indicates the nozzle number and the numeral on the right indicates the recording order (the number of the main scan in which it was recorded).

The interlace scheme shown in FIG. **27** is characterized by the configuration of the nozzle array of the recording head and the sub-scanning method. Specifically, in the interlace scheme, the nozzle pitch k indicating the interval between the centers of adjacent nozzles is defined as an integer at least 2, while the number of nozzles N and the nozzle pitch k are selected as integers which are relatively prime. Two integers are "relatively prime" when they do not have a common divisor other than 1. Further, sub-scanning pitch L is set at a constant value given by $N/(D\cdot k)$.

The interlace scheme makes irregularities in nozzle pitch and ink jetting feature to thin out over the recorded image. Because of this, it improves image quality by mitigating the effect of any irregularity that may be present in the nozzle pitch, the jetting feature and the like.

The "overlap scheme", also known as the "multi-scan scheme", taught for example by Japanese Patent Laid-Open Gazette No. 3-207665 and Japanese Patent Publication Gazette No. 4-19030 is another technique used to improve image quality in color ink jet printers.

FIG. **28** is a diagram for explaining an example of the overlap scheme. In the overlap scheme, 8 nozzles are divided into 2 nozzle sets. The first nozzle set is made up of 4 nozzles having even nozzle numbers (left numeral in each circle) and the second nozzle set is made up of 4 nozzles having odd nozzle numbers. In each main scan, the nozzle sets are each intermittently driven to form dots in the main scanning direction once every (s) dots. Since s=2 in the example of FIG. **28**, a dot is formed at every second dot position. The timing of the driving of the nozzle sets is controlled so that the each nozzle set forms dots at different positions from the other in the main scanning direction. In other words, as shown in FIG. **28**, the recording positions of the nozzles of the first nozzle set (nozzles number **8**, **6**, **4**, **2**) and those of the nozzles of the second nozzle set (nozzles number **7**, **5**, **3**, **1**) are offset from each other by 1 dot in the main scanning direction. This kind of scanning is conducted multiple times with the nozzle driving times being offset between the nozzle sets during each main scan to form all dots on the main scanning lines.

In the overlap scheme, the nozzle pick k is set at an integer at least 2, as in the interlace scheme. However, the number of nozzles N and the nozzle pitch k are not relatively prime, but the nozzle pitch k and the value N/s, which is obtained by dividing the number of nozzles N by the number of scan repeats, are set at relatively prime integers instead.

In the overlap scheme, the dots of each main scanning line are not all recorded by the same nozzle but by multiple nozzles. Even when the nozzle characteristics (pitch, jetting feature etc.) are not completely uniform, therefore, enhanced image quality can be obtained because the characteristics of the individual nozzles is prevented from affecting the entire main scanning line.

However, what is the preferred printing scheme in terms of improving the quality of the printed image differs depending on the arrangement of the print head nozzle array. This means that for a specific print head, it can be difficult to set a printing scheme for improving the quality.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide a printing technique that makes it possible to obtain high image quality with a specific print head.

The present invention is directed to a printing technique using a printing apparatus having a sub-scanning drive section includes a first sub-scanning drive mechanism that effects sub-scan feeding at a relatively high precision, and a second sub-scanning drive mechanism that effects sub-scan feeding at a relatively low precision after completion of sub-scan feeding by at least the first sub-scanning drive mechanism. A print head is provided with a first array of a plurality of dot formation element groups that are arrayed in a prescribed order in the sub-scanning direction. The first array includes a group of yellow dot formation elements for forming yellow dots. The plurality of dot formation element groups of the first array are arrayed in an order that is determined so that at an arbitrary point on the print medium yellow dots are formed after dots of other colors. Each of the plurality of dot formation element groups has a mutually equal number of dot formation elements When the print medium is being fed in a sub-scanning direction not by the first sub-scanning drive mechanism but by the second sub-scanning drive mechanism, printing in the vicinity of the trailing edge of the print medium is effected using the group of yellow dot formation elements but not the other groups of the first array.

In accordance with this invention, printing in the vicinity of the trailing edge of the print medium is effected using only the yellow dot formation elements of the first array that are used to form yellow dots. In the vicinity of the trailing edge sub-scan feeding of the print medium is effected not by the first sub-scanning drive mechanism but by the second sub-scanning drive mechanism, which has a relatively low feed precision. However, yellow dots are relatively inconspicuous, so even though the sub-scanning feed precision is lower, it does not have much of an adverse effect on image quality. Thus, the invention makes it possible to execute printing that enables high image quality to be obtained in respect of the specific print head.

When the print medium is being fed proximate the trailing edge of the print medium in a sub-scanning direction not by the first sub-scanning drive mechanism but by the second sub-scanning drive mechanism, sub-scanning feeding may be effected by the second sub-scanning drive mechanism at the same feed amounts by which feeding has been effected by the first sub-scanning drive mechanism. This enables the printing process to be continued without adjusting the sub-scan feeding, thereby simpifying control of the scanning.

The print head may further include a second array of dot formation elements, disposed parallel to the first array, having a group of black dot formation elements for forming black dots. The second array may be arranged to form dots on the print medium prior to the first array. The group of black dot formation elements includes a plurality of dot formation elements disposed at the same sub-scanning positions as the plurality of dot formation element groups of the first array. During color printing the formation of black dots is implemented using only black dot formation elements located at the same sub-scanning positions as chromatic color dot formation elements in use of a specific chromatic color dot formation element group of the first dot formation element array, where the specific chromatic color dot formation element group is a group that can print dots before the other dot formation element groups of the first array. Thus, at each location on the print medium black dots are formed earlier than dots of other colors, which prevents bleeding of the black dots and thereby makes it possible to obtain color images of a high chroma.

The first and second arrays may formed within an identical actuator. As it thus becomes possible to position adjacent dot formation elements with good precision, image quality can be improved.

The present invention is also directed to a print head for use in a printing apparatus that prints images by forming dots on a print medium. The print head comprises: a first array of a plurality of dot formation element groups that are arrayed in a prescribed order in a sub-scanning direction. The first array includes a group of yellow dot formation elements for forming yellow dots. Each of the plurality of dot formation element groups has a mutually equal number of dot formation element. The group of yellow dot formation elements is arranged at an end of the first array. With this print head, yellow dots can be formed in the vicinity of a trailing edge of a print medium after dots of other colors are formed thereon. Since yellow dots are relatively inconspicuous, even if sub-scanning feed precision is lower in the vicinity of the trailing edge of the print medium, it does not have much of an adverse effect on image quality.

Specific aspects of the invention can be applied to various types of printing apparatus, printing methods, computer. program products, and print heads.

These and other objects, features, aspects, and advantages of the present invention will become more apparent from the following detailed description of the preferred embodiments with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a general perspective view of the main structure of a color inkjet printer **20** which is an embodiment of the invention.

FIG. **2** is a block diagram of the electrical system of the printer **20**.

FIG. **3** shows the arrangement of the nozzles formed in the bottom surface of an actuator **40**.

FIG. **4** illustrates the basic arrangement of the sub-scanning drive section used to transport paper P.

FIGS. **5**(A) and **5**(B) show the basic conditions of a dot printing scheme in which the number of scan repeats is one.

FIGS. **6**(A) and **6**(B) show the basic conditions of a dot printing scheme in which the number of scan repeats is two or more.

FIG. **7** shows the scanning parameters of a printing scheme according to a first embodiment of the invention.

FIG. **8** shows the nozzles used in the first embodiment.

FIG. **9** is an explanatory diagram of the nozzles used in the first embodiment to form the raster lines during each pass within the effective printing area.

FIG. **10** shows the nozzles used in a first comparative example.

FIG. **11** is an explanatory diagram of the nozzles used in the first comparative example to form the raster lines during each pass within the effective printing area.

FIG. **12** shows an equivalent nozzle positioning arrangement.

FIG. **13** shows the relationship between the actuator **40** and the low-precision area LPA at the trailing edge of the printing area PA of the paper P.

FIG. **14** shows the scanning parameters of a printing scheme according to a second embodiment of the invention.

FIG. **15** shows the nozzles used in the second embodiment.

FIG. **16** is an explanatory diagram of the nozzles used in the second embodiment to form the raster lines during each pass within the effective printing area.

FIG. **17** shows the nozzles used in a second comparative example.

FIG. **18** is an explanatory diagram of the nozzles used in the second comparative example to form the raster lines during each pass within the effective printing area.

FIG. **19** shows a first actuator variation.

FIG. **20** shows a second actuator variation.

FIG. **21** shows a third actuator variation.

FIG. **22** shows a fourth actuator variation.

FIG. **23** shows a fifth actuator variation.

FIG. **24** shows a sixth actuator variation.

FIG. **25** shows a seventh actuator variation.

FIG. **26** shows a eighth actuator variation.

FIG. **27** shows an example of an interlaced printing scheme.

FIG. **28** shows an example of an overlapping printing scheme.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A. General Configuration of the Apparatus

FIG. **1** is a general perspective view of the configuration of a color inkjet printer **20** which is an embodiment of the invention. The printer **20** includes a paper stacker **22**, a feed roller **24** driven by a step motor (not shown), a platen **26**, a carriage **28**, a step motor **30**, a drive belt **32** driven by the step motor **30**, and guide rails **34** for the carriage **28**. Mounted on the carriage **28** is a print head **36** that has a plurality of nozzles.

The feed roller **24** draws paper P from the stacker **22** and feeds the paper in the sub-scanning direction over the face of the platen **26**. The carriage **28** is moved along the guide rails **34** by the action of the drive belt **32** driven by the step motor **30**. The main scanning direction is perpendicular to the sub-scanning direction.

FIG. **2** is a block diagram of the electrical system of the printer **20**. The printer **20** includes a receive buffer memory **50** for receiving signals from a host computer **100**, an image buffer memory **52** for storing printing data, and a system controller **54** that controls the overall operation of the printer **20**. Connected to the system controller **54** are a main scanning driver **61** for the carriage motor **30**, a sub-scanning driver **62** for a feed motor **31**, and a head driver **63** for the print head **36**.

Based on the printing scheme specified by a user, a printer driver (not shown) of the host computer **100** determines the various parameters that define the printing operations. Based on these parameters, the printer driver generates the printing data needed to effect the printing by the printing scheme concerned, and transfers the printing data to the printer **20**, where it is placed in the receive buffer memory **50**. The system controller **54** reads the required information contained in the printing data and based on that information sends control signals to the drivers **61**, **62** and **63**.

The printing data is broken down into the individual color components to obtain image data for each color component which is stored in the receive buffer memory **50**. In accordance with the control signals from the system controller **54**, the head driver **63** reads out the color component image data from the image buffer memory **52** and uses the data to drive the array of nozzles on the print head **36**.

B. Print Head Configuration

FIG. **3** illustrates the arrangement of the nozzles formed in the bottom surface of an actuator **40** provided on the lower part of the print head **36**. These nozzles comprise a straight row (array) of color nozzles and a straight row of black nozzles, each arrayed in the sub-scanning direction. Here, "actuator" refers to an ink emission structure that includes nozzles and drive elements for emitting ink such as, for example, piezo-electric elements or heaters. Generally, an actuator nozzle portion is formed in one piece of ceramics. Forming two rows of nozzles in one actuator allows the nozzles to be positioned precisely, resulting in improved image quality.

The array of black nozzles comprises 48 nozzles numbered #K**1** to #K**48**, arrayed in the sub-scanning direction at a constant nozzle pitch k. The nozzle pitch k is six dots. However, for the dot pitch on the paper P, this pitch k may be set at a value that is a multiple of any integer of two or more.

The array of color nozzles includes a group of yellow nozzles **40**Y, a group of magenta nozzles **40**M and a group of cyan nozzles **40**C. Herein, groups of color nozzles are also referred to as groups of chromatic color nozzles. The group of yellow nozzles **40**Y has 15 nozzles, numbered #Y**1** to #Y**15**, arrayed at the same pitch k as the black nozzles. The same also applies to the group of magenta nozzles **40**M and the group of cyan nozzles **40**C. The "x" mark between the lowermost of the yellow nozzles, nozzle #Y**15**, and the topmost of the magenta nozzles, nozzle #M**1**, indicates that

there is no nozzle formed at that position. Therefore, the space between nozzles #Y**15** and #M**1** is twice the nozzle pitch k. This also applies to the space between nozzle #M**15** and #C**1**. That is to say, the spacing between the groups of yellow, magenta and cyan nozzles is set at twice the nozzle pitch k.

Like the array of black nozzles **40**K, the nozzles of the color nozzle groups **40**Y, **40**M and **40**C are arrayed in the sub-scanning direction. However, in the case of the chromatic color nozzle array, there are no nozzles at the positions corresponding to the 16th, 32nd and 48th black nozzles #K**16**, #K**32** and #K**48**.

During printing, droplets of ink are expelled from the nozzles as the print head **36** and carriage **28** are moved in the main scanning direction. Depending on the printing scheme, a portion rather than all of the nozzles may be used.

C. Configuration of the Sub-scanning Drive Mechanism

FIG. **4** illustrates the basic arrangement of the sub-scanning drive section used to transport paper P. This section comprises a first sub-scanning drive mechanism **25** provided at the paper supply end, and a second sub-scanning drive mechanism **27** provided at the paper outlet end. The first sub-scanning drive mechanism **25** is constituted by a feed roller **25***a* and an idle roller **25***b*, while the second sub-scanning drive mechanism **27** is constituted by an outlet roller **27***a* and a serrated roller **27***b*. The rollers **25***a*, **25***b*, **27***a* and **27***b* are driven by the rotation of the feed motor **31** transmitted by a gear train (not shown). At the start of printing, the rotation of the rollers **25***a* and **25***b* transports paper P from the supply end (on the right in FIG. **4**). The leading edge of the paper P is gripped between the rollers **27***a* and **27***b* to thereby be transported to the outlet side. After the trailing edge of the paper P has passed beyond the gripping point of the rollers **25***a* and **25***b*, it is transported by just the second sub-scanning drive mechanism **27**. The print head **36** prints images on the paper P when the paper is over the platen **26**.

In this printer, the feed precision of the first sub-scanning drive mechanism **25** is higher than that of the second sub-scanning drive mechanism **27**. As such, when the trailing edge of the paper P has passed beyond the gripping point of the rollers of the first sub-scanning drive mechanism **25** and is therefore being transported by just the second sub-scanning drive mechanism **27**, the feed precision is lower compared to when the paper is being transported by the first sub-scanning drive mechanism **25**.

In FIG. **4**, **40**W denotes the overall width of the nozzle array in the sub-scanning direction, and WLP denotes the width of the group of yellow nozzles **40**Y. This width WLP corresponds to the width of a low precision area, described hereinbelow. WB denotes the distance from the gripping point of the first sub-scanning drive mechanism **25** to the trailing edge of the nozzle arrays. Herein, the leading and trailing edges of the paper and nozzle arrays are defined with respect to the direction in which the paper is fed (the sub-scanning direction). Also, the paper feed direction and sub-scanning direction are defined in terms of the direction in which the paper moves relative to the printer **20** during sub-scanning. Leading edge may also be referred to as upper end or edge, and trailing edge may also be referred to lower end or edge.

D. Basic Conditions of General Recording Scheme

Before describing the dot recording schemes used in the embodiment of the present invention, the following describes basic conditions required for general printing schemes. In this specification, "dot recording scheme" and "printing scheme" have the same meaning.

FIGS. 5(A) and 5(B) show basic conditions of a general dot recording scheme when the number of scan repeats is equal to one. FIG. 5(A) illustrates an example of sub-scan feeds with four nozzles, and FIG. 5(B) shows parameters of the dot recording scheme. In the drawing of FIG. 5(A), solid circles including numerals indicate the positions of the four nozzles in the sub-scanning direction after each sub-scan feed. The encircled numerals **0** through **3** denote the nozzle numbers. The four nozzles are shifted in the sub-scanning direction every time when one main scan is concluded. Actually, however, the sub-scan feed is executed by feeding a printing paper with the sheet feed motor **23** (FIG. **2**).

As shown on the left-hand side of FIG. 5(A), the sub-scan feed amount L is fixed to four dots. On every sub-scan feed, the four nozzles are shifted by four dots in the sub-scanning direction. When the number of scan repeats s is equal to one, each nozzle can record all dots (pixels) on the raster line. The right-hand side of FIG. 5(A) shows the nozzle numbers of the nozzles which record dots on the respective raster lines. There are non-serviceable raster lines above or below those raster lines that are drawn by the broken lines, which extend rightward (in the main scanning direction) from a circle representing the position of the nozzle in the sub-scanning direction. Recording of dots is thus prohibited on these raster lines drawn by the broken lines. On the contrary, both the raster lines above and below a raster line that is drawn by the solid line extending in the main scanning direction are recordable with dots. The range in which all dots can be recorded is hereinafter referred to as the "effective record area" (or the "effective print area"). The range in which the nozzles scan but all the dots cannot be recorded are referred to as the "non-effective record area (or the "non-effective print area)". All the area which is scanned with the nozzles (including both the effective record area and the non-effective record area) is referred to as the nozzle scan area.

Various parameters related to the dot recording scheme are shown in FIG. 5(B). The parameters of the dot recording scheme include the nozzle pitch k [dots], the number of used nozzles N, the number of scan repeats s, number of effective nozzles Neff, and the sub-scan feed amount L [dots].

In the example of FIGS. 5(A) and 5(B), the nozzle pitch k is 3 dots, and the number of used nozzles N is 4. The number of used nozzles N denotes the number of nozzles actually used among the plurality of nozzles provided. The number of scan repeats s indicates that dots are formed intermittently once every s dots on a raster line during a single main scan. The number of scan repeats s is accordingly equal to the number of nozzles used to record all dots of each raster line. In the case of FIGS. 5(A) and 5(B), the number of scan repeats s is 1. The number of effective nozzles Neff is obtained by dividing the number of used nozzles N by the number of scan repeats s. The number of effective nozzles Neff may be regarded as the net number of raster lines that can be fully recorded during a single main scan. The meaning of the number of effective nozzles Neff will be further discussed later.

The table of FIG. 5(B) shows the sub-scan feed amount L, its accumulated value ΣL, and a nozzle offset F after each sub-scan feed. The offset F is a value indicating the distance in number of dots between the nozzle positions and reference positions of offset 0. The reference positions are presumed to be those periodic positions which include the initial positions of the nozzles where no sub-scan feed has been conducted (every fourth dot in FIG. 5(A)). For example, as shown in FIG. 5(A), a first sub-scan feed moves the nozzles in the sub-scanning direction by the sub-scan feed amount L (4 dots). The nozzle pitch k is 3 dots as mentioned above. The offset F of the nozzles after the first sub-scan feed is accordingly 1 (see FIG. 5(A)). Similarly, the position of the nozzles after the second sub-scan feed is ΣL(=8) dots away from the initial position so that the offset F is 2. The position of the nozzles after the third sub-scan feed is ΣL(=12) dots away from the initial position so that the offset F is 0. Since the third sub-scan feed brings the nozzle offset F back to zero, all dots of the raster lines within the effective record area can be serviced by repeating the cycle of 3 sub-scans.

As will be understood from the above example, when the nozzle position is apart from the initial position by an integral multiple of the nozzle pitch k, the offset F is zero. The offset F is given by (ΣL) %k, where ΣL is the accumulated value of the sub-scan feed amount L, k is the nozzle pitch, and "%" is an operator indicating that the remainder of the division is taken. Viewing the initial position of the nozzles as being periodic, the offset F can be viewed as an amount of phase shift from the initial position.

When the number of scan repeats s is one, the following conditions are required to avoid skipping or overwriting of raster lines in the effective record area:

Condition c**1**: The number of sub-scan feeds in one feed cycle is equal to the nozzle pitch k.

Condition c**2**: The nozzle offsets F after the respective sub-scan feeds in one feed cycle assume different values in the range of 0 to (k−1).

Condition c**3**: Average sub-scan feed amount (ΣL/k) is equal to the number of used nozzles N. In other words, the accumulated value ΣL of the sub-scan feed amount L for the whole feed cycle is equal to a product (N×k) of the number of used nozzles N and the nozzle pitch k.

The above conditions can be understood as follows. Since (k−1) raster lines are present between adjoining nozzles, the number of sub-scan feeds required in one feed cycle is equal to k so that the (k−1) raster lines are serviced during one feed cycle and that the nozzle position returns to the reference position (the position of the offset F equal to zero) after one feed cycle. If the number of sub-scan feeds in one feed cycle is less than k, some raster lines will be skipped. If the number of sub-scan feeds in one feed cycle is greater than k, on the other hand, some raster lines will be overwritten. The first condition c**1** is accordingly required.

If the number of sub-scan feeds in one feed cycle is equal to k, there will be no skipping or overwriting of raster lines to be recorded only when the nozzle offsets F after the respective sub-scan feeds in one feed cycle take different values in the range of 0 to (k−1). The second condition c**2** is accordingly required.

When the first and the second conditions c**1** and c**2** are satisfied, each of the N nozzles records k raster lines in one feed cycle. Namely N×k raster lines can be recorded in one feed cycle. When the third condition c**3** is satisfied, the nozzle position after one feed cycle (that is, after the k sub-scan feeds) is away from the initial position by the N×k raster lines as shown in FIG. 5(A). Satisfying the above first through the third conditions c**1** to c**3** thus prevents skipping or overwriting of raster lines to be recorded in the range of N×k raster lines.

FIGS. 6(A) and 6(B) show the basic conditions of a general dot recording scheme when the number of scan repeats s is at least 2. When the number of scan repeats s is 2 or greater, each raster line is recorded with s different nozzles. In the description hereinafter, the dot recording scheme adopted when the number of scan repeats s is at least 2 is referred to as the "overlap scheme".

The dot recording scheme shown in FIGS. **6**(A) and **6**(B) amounts to that obtained by changing the number of scan repeats s and the sub-scan feed amount L among the dot recording scheme parameters shown in FIG. **5**(B). As will be understood from FIG. **6**(A), the sub-scan feed amount L in the dot recording scheme of FIGS. **6**(A) and **6**(B) is a constant value of two dots. In FIG. **6**(A), the nozzle positions after the odd-numbered sub-scan feeds are indicated by the diamonds. As shown on the right-hand side of FIG. **6**(A), the dot positions recorded after the odd-numbered sub-scan feed are shifted by one dot in the main scanning direction from the dot positions recorded after the even-numbered sub-scan feed. This means that the plurality of dots on each raster line are recorded intermittently by each of two different nozzles. For example, the upper-most raster in the effective record area is intermittently recorded on every other dot by the No. **2** nozzle after the first sub-scan feed and then intermittently recorded on every other dot by the No. **0** nozzle after the fourth sub-scan feed. In the overlap scheme, each nozzle is generally driven at an intermittent timing so that recording is prohibited for (s−1) dots after recording of one dot during a single main scan.

In the overlap scheme, the multiple nozzles used for recording the same raster line are required to record different positions shifted from one another in the main scanning direction. The actual shift of recording positions in the main scanning direction is thus not restricted to the example shown in FIG. **6**(A). In one possible scheme, dot recording is executed at the positions indicated by the circles shown in the right-hand side of FIG. **6**(A) after the first sub-scan feed, and is executed at the shifted positions indicated by the diamonds after the fourth sub-scan feed.

The lower-most row of the table of FIG. **6**(B) shows the values of the offset F after each sub-scan feed in one feed cycle. One feed cycle includes six sub-scan feeds. The offsets F after each of the six sub-scan feeds assume every value between 0 and 2, twice. The shift in the offset F after the first through the third sub-scan feeds is identical with that after the fourth through the sixth sub-scan feeds. As shown on the left-hand side of FIG. **6**(A), the six sub-scan feeds included in one feed cycle can be divided into two sets of sub-cycles, each including three sub-scan feeds. One feed cycle of the sub-scan feeds is completed by repeating the sub-cycles s times.

When the number of scan repeats s is an integer of at least 2, the first through the third conditions **c1** to **c3** discussed above are rewritten into the following conditions **c1**' through **c3**':

Condition **c1**': The number of sub-scan feeds in one feed cycle is equal to a product (k×s) of the nozzle pitch k and the number of scan repeats s.

Condition **c2**': The nozzle offsets F after the respective sub-scan feeds in one feed cycle assume every value between 0 to (k−1), s times.

Condition **c3**': Average sub-scan feed amount {ΣL/(k×s)} is equal to the number of effective nozzles Neff (=N/s). In other words, the accumulated value ΣL of the sub-scan feed amount L for the whole feed cycle is equal to a product {Neff×(k×s)} of the number of effective nozzles Neff and the number of sub-scan feeds (k×s).

The above conditions **c1**' through **c3**' hold even when the number of scan repeats s is one. This means that the conditions **c1**' through **c3**' generally hold for the dot recording scheme irrespective of the number of scan repeats s. When these three conditions **c1**' through **c3**' are satisfied, there is no skipping or overwriting of dots recorded in the effective record area. If the overlap scheme is applied (if the number of scan repeats s is at least 2), the recording positions on the same raster should be shifted from each other in the main scanning direction.

Partial overlapping may be applied for some recording schemes. In the "partial overlap" scheme, some raster lines are recorded by one nozzle and other raster lines are recorded by multiple nozzles. The number of effective nozzles Neff can be also defined in the partial overlap scheme. By way of example, if two nozzles among four used nozzles cooperatively record one identical raster line and each of the other two nozzles records one raster line, the number of effective nozzles Neff is 3. The three conditions **c1**' through **c3**' discussed above also hold for the partial overlap scheme.

It may be considered that the number of effective nozzles Neff indicates the net number of raster lines recordable in a single main scan. For example, when the number of scan repeats s is 2, N raster lines can be recorded by two main scans where N is the number of actually-used nozzles. The net number of raster lines recordable in a single main scan is accordingly equal to N/S (that is, Neff). The number of effective nozzles Neff in this embodiment corresponds to the number of effective dot forming elements in the present invention.

E. First Embodiment of the Printing Scheme

FIG. **7** shows the scanning parameters used in a first embodiment of the printing scheme of the invention. In this first embodiment, the nozzle pitch k is six dots, the number of scan repeats is one, the number of working nozzles N is 13 and the number of effective nozzles Neff is 13.

The table in FIG. **7** lists the parameters for each of the first through seventh passes. Herein, a main scan is also referred to as a pass. For each pass, the table shows the sub-scan feed amount L just prior to the pass, the cumulative feed value ΣL and the offset F. The sub-scan feed amount L is a fixed value of 13 dots. This printing scheme (scanning scheme) in which L is a fixed value is referred to as a set feed scheme. The scanning parameters of the first embodiment satisfy the aforementioned conditions **c1**' to **c3**'.

FIG. **8** is a diagram illustrating the nozzles used. in the first embodiment. The actuator **40** shown in FIG. **8** is the same as the one shown in FIG. **3**, but in the first embodiment only some of the nozzles are used. The open circles indicate the nozzles that are used, and the solid circles indicate the nozzles that are not used. Thus, of the 15 nozzles for each chromatic color ink, just the first 13 are used. With respect to black ink, just the 13 nozzles in the sub-scanning locations corresponding to the cyan nozzles #C**1** to #C**13** are used. With the same number of nozzles being used for each of the four inks, by scanning using the same parameters for all nozzles, dots of each color can be formed without voids or undesired overlaps.

Herein, the groups of nozzles used for each ink are also referred to as working nozzle groups. Also, the groups of nozzles provided on the actuator **40** for each ink are also referred to as implemented nozzle groups.

Nozzles arrayed at nozzle pitch k are selected to serve as the working nozzles. The nozzle **#Y13** at the lower end of the group of yellow nozzles and the nozzle **#M1** at the upper end of the group of magenta nozzles are separated by a space that is four times the nozzle pitch k (4k), meaning **24** dots. The nozzle **#M13** at the lower end of the group of magenta nozzles and the nozzle #C**1** at the upper end of the group of cyan nozzles are also separated by 4k.

With respect to the first embodiment, FIG. **9** is an explanatory diagram of the nozzles used to form the raster lines during each pass, within the effective printing area. In pass **1**, nozzles #C**11**, #C**12** and #C**13** form dots on the effective raster lines **1**, **7** and **13**, respectively. An effective raster line is a raster line within the effective printing area. In FIG. **9**, the symbol "#" that precedes nozzle numbers is omitted. Hatching indicates nozzles that are not being used. The symbol "×" indicates a location between adjacent groups of working nozzles where there is no nozzle.

For pass **2**, the target printing position of the actuator **40** is moved the equivalent of 13 dots away from pass **1** in the sub-scanning direction. In this embodiment the nozzle pitch k is **6**, so after the sub-scanning feed, the nozzle position offset F (what remains after the cumulative feed ΣL is divided by k) is one dot. In the case of pass **2**, therefore, the target raster line appear to be one line below the target raster line of pass **1**. In fact, of course, the target raster line for the same nozzle is 13 lines below. In this first embodiment the sub-scanning feed amount L is fixed at 13 dots, so that each time a sub-scanning feed is effected, the position of the target raster line appears to move down one line.

As explained below, with respect to cyan, the cumulative feed error in the sub-scanning direction reaches a maximum at Cmis between raster lines **6** and **7**. Raster line **6** is printed on pass **6**, while raster line **7** is printed during pass **1**. This means that there are five sub-scanning feeds between the printing of raster line **7** during pass **1** and the printing of raster line **6** on pass **6**, resulting in the accumulation of the errors of the five feeds. This accumulation of the errors of five feeds also happens between cyan raster lines **12** and **13**.

The same type of observation reveals that in the case of magenta, too, the cumulative feed error becomes relatively large at Mmis between raster lines **7** and **8**. Similarly, in the case of yellow the cumulative feed error becomes relatively large at Ymis between raster lines **7** and **8**. Hereinbelow the position at which the cumulative value of the sub-scanning feed error becomes relatively large is referred to as the accumulated error position.

As can be understood from the above explanation, in the case of the first embodiment the accumulated error position is different for each chromatic color ink. Accumulated error positions are more prone to the formation of banding, which are lines that extend in the main scanning direction, degrading the image quality. However, since in accordance with this first embodiment the accumulated error position is different for each ink color, banding at these positions is less noticeable.

FIG. **10** shows the actuator used in a first comparative example. The actuator **40'** is comprised of a group of 13 yellow nozzles **40Y'**, a group of 13 magenta nozzles **40M'** and a group of 13 cyan nozzles **40C'**. The spacing between the adjacent end nozzles of the groups is the same as the nozzle pitch k. That is, on the actuator **40'** of FIG. **10** the 13 nozzles of each chromatic color used in the arrangement of the first embodiment are arrayed at a nozzle pitch k. The group of black ink nozzles **40K'** comprises 39 nozzles, also arrayed at pitch k. The arrangement of this first comparative example uses this actuator **40'** to effect printing in accordance with the same scanning parameters as those of the first embodiment shown in FIG. **7**.

FIG. **11** is an explanatory diagram showing the nozzles used to form the raster lines during each pass, within the effective printing area, in the case of the first comparative example. The accumulated error positions Cmis, Mmis, Ymis of the three chromatic color inks all fall between raster lines **6** and **7** and between raster lines **12** and **13**. In this case banding tends to be more noticeable, and is therefore highly likely to degrade the image quality.

As can be seen from a comparison between the working nozzles of FIGS. **8** and **10**, the only difference between the first embodiment and the first comparative example is the spacing between the groups of working nozzles. Specifically, in the case of the first embodiment the spacing between the groups is set at 4k (four times the nozzle pitch k) while in the case of the first comparative example the spacing is the same as the nozzle pitch k. This difference in the spacing between the groups of working nozzles is manifested in the differences between the accumulated error positions Cmis, Mmis and Ymis seen in FIGS. **9** and **11**.

To avoid as far as possible the accumulated error positions of adjacent nozzle groups coinciding in the sub-scanning direction, it is desirable to use a selection of working nozzles that results in the spacing between adjacent groups of working nozzles being M times the nozzle pitch k, where M is an integer of 2 or more.

However, it is also desirable for the spacing between adjacent groups of working nozzles to be set as follows. FIG. **12** illustrates an equivalent nozzle positioning arrangement used in the printing scheme of FIG. **5**(A). As also explained with reference to FIG. **5**(A), when the number of scan repeats is one, one scanning cycle includes k sub-scanning feeds. Therefore, the amount by which the nozzle group is moved by the sub-scanning feed of one cycle is N×k raster lines. FIG. **12** shows the initial position of the nozzle group in each of the first through third cycles. Since the same printing operation is implemented from these three nozzle group positions, the positions are mutually equivalent. The spacing between the nozzle at the lower end at the initial position in the first cycle and the nozzle at the upper end at the initial position in the second cycle is k dots. Also, the spacing between the nozzle at the lower end at the initial position in the first cycle a nd the nozzle at the upper end at the initial position in the third cycle is (N×k+k) dots. While not illustrated, it can be understood that the spacing between the nozzle at the lower end at the initial position in the first cycle and the nozzle at the upper end at the initial position in the fourth cycle will be (2×N×k+k) dots. Normally the spacing between the nozzle at the lower end at the initial position in the first cycle and the nozzle at the upper end of another equivalent nozzle group is expressed as (N×n+1)k dots. Here, n is an arbitrary integer of zero or more.

When working nozzle groups used for different inks are disposed in the type of equivalent positional arrangement shown in FIG. **12**, the result is a mutual coincidence of the accumulated error positions in respect of those inks. To prevent this happening, it is desirable to set the spacing between adjacent groups of working nozzles to a value other than (N×n+1) k dots (N being the number of working nozzles and n an arbitrary integer of one or more). Here, n is specified as being one or more rather than zero or more because if, as described above, the spacing between adjacent groups of working nozzles is M times the nozzle pitch k, where M is an integer of 2 or more, n=0 would be excluded.

The first embodiment also has the following features. As seen from the above-described FIG. **8**, during main scanning the array of black nozzles **40K** precedes the arrays of color nozzles, so during color printing black dots are printed before dots of other colors. Also, in the sub-scanning direction the color nozzles are arrayed in the order cyan nozzles **40C**, then magenta nozzles **40M**, then yellow nozzles **40Y**, meaning that chromatic color dots are formed in that order. Moreover, with respect to the group of working nozzles used for black, the only nozzles used are those provided in the same sub-scanning locations as the group of cyan working nozzles disposed on the trailing edge in the sub-scanning direction.

In effecting color printing in accordance with the first embodiment, this feature of the actuator **40** gives rise to the following various advantages or benefits. The first advantage is that black dots are formed before the dots of the other inks. When black dots are formed after instead of before dots of other colors, the black ink tends to bleed, lowering the chroma of the color image. Chroma degradation is particularly conspicuous when there is bleeding between black and yellow inks. By selecting the working nozzle group arrangement shown in FIG. **8**, at any arbitrary position within the printing area black dots are formed before the dots of the other colors, making it possible to improve the chroma of the color images.

A second advantage is that, at any arbitrary position within the printing area, yellow dots are formed after the dots of other colors. As can be seen from FIG. **8**, when the paper P is being transported in the sub-scanning direction, at any arbitrary point within the printing area PA, black dots will first be formed, followed by cyan dots, then magenta dots, and finally yellow dots. With reference to FIG. **4**, after the trailing edge of the paper P has cleared the gripping point of the first sub-scanning drive mechanism **25** (the point of contact between the rollers **25***a* and **25***b*), the paper is transported only by the second sub-scanning drive mechanism **27**, which has a relatively low feed precision in the sub-scanning direction. As a result, when yellow dots are being formed in the low-precision area, which has the same width as the width WLP of the group of yellow nozzles **40**Y, the paper is being fed in the sub-scanning direction with a relatively low precision.

FIG. **13** shows the relationship between the actuator **40** and the low-precision area LPA at the trailing edge of the printing area PA of the paper P. While yellow dots are being formed within this low-precision area, the paper is being moved in the sub-scanning direction by the second sub-scanning drive mechanism **27** at a relatively low precision. Here, low-precision area LPA refers to an area in which the sub-scanning feed has a low precision. The width of the low-precision area LPA is the same as the width of the group of yellow nozzles **40**Y as measured in the sub-scanning direction.

At the point in time shown by FIG. **13**, the formation of black, magenta and cyan dots in the low-precision area LPA has been completed. From this point, therefore, only yellow dots will be formed in the area LPA. However, since yellow dots do not stand out as much as dots of the other three colors, even if there is some deviation in the location of the yellow dots caused by the low precision of the sub-scanning feed, it will not have much of an adverse effect on the image quality. Thus, there is the advantage that when the paper is being fed in the sub-scanning direction by just the second sub-scanning drive mechanism **27**, the only dots being formed in the low-precision area LPA are yellow dots, so there is little degradation in image quality.

However, the printing process used to in the vicinity of the leading or trailing edges of the paper is usually a different one to that used in the intermediate portion of the printing area. Herein, the printing process used in the vicinity of the trailing edge of the printing area is referred to as trailing edge or lower edge processing, and the printing process used in the intermediate part of the printing area is referred to as intermediate processing. In lower edge processing, to prevent any excessive decrease in sub-scanning feed precision, the feed amounts used are smaller than those used when printing in the mid-part of the printing area. An example of lower edge processing technology is disclosed by the present applicant in JPA Hei 7-242025. FIG. **9** of the disclosure shows the intermediate part of the printing area printed using an interlaced printing scheme, and lower edge processing using fine feeding in which the feed is in single dot increments.

In the present invention lower edge processing is not used when printing yellow dots in the low-precision area LPA. Instead, the sub-scanning feed amounts used are the same as that used for the intermediate processing. Specifically, the feed amounts shown in FIG. **7** are used when printing yellow dots in the low-precision area LPA. In other words, the feed amounts used when the paper is being fed by just the second sub-scanning drive mechanism **27** are the same as those effected using the first sub-scanning drive mechanism **25**. This has the advantage of simplifying the control of the sub-scanning feed. Yellow dots are not so noticeable as dots of the other colors, so non-use of lower edge processing does not result in much of a deterioration in the image quality.

F. Second Embodiment of the Printing Scheme

FIG. **14** shows the scanning parameters used in a second embodiment of the printing scheme of the invention. In this second embodiment, the nozzle pitch k is six dots, the number of scan repeats is one, the number of working nozzles N is 15 and the number of effective nozzles Neff is 15.

The table in FIG. **14** shows the parameters for each of the first through seventh passes. Three sub-scan feed amounts L are used, which are 14, 15 and 16 dots. This printing scheme (scanning scheme) in which a plurality of L values is used is referred to as a variable feed scheme. The scanning parameters of the second embodiment satisfy the aforementioned conditions **c1'** to **c3'**.

FIG. **15** illustrates the nozzles used in the second embodiment. The actuator **40** shown in FIG. **15** is the same as the one shown in FIG. **3**. All of the 15 nozzles of each chromatic ink color are used. With respect to black ink, just the 15 nozzles in the sub-scanning locations corresponding to the cyan nozzles #C1 to #C15 are used. The nozzle #Y15 at the lower end of the group of yellow nozzles and the nozzle **#M1** at the upper end of the group of magenta nozzles are separated by an amount that is two times the nozzle pitch k (2k). Similarly, the separation between the nozzle **#M15** at the lower end of the group of magenta nozzles and the nozzle **#C1** at the upper end of the group of cyan nozzles is also 2k.

In color printing, the second embodiment provides the following advantages. First, the black dots are formed before the dots of the other colors, making it possible to print color images with a high chroma. The second advantage is that in the low-precision area LPA (FIG. **13**) only yellow dots are printed, so a lower sub-scanning feed precision does not have much of an adverse effect on image quality. In this embodiment, too, when the paper is being fed in the sub-scanning direction by just the second sub-scanning drive mechanism **27**, it can be fed by the same amounts (the feed amounts shown in FIG. **14**) used as when the paper is being fed by the first sub-scanning drive mechanism **25**.

With respect to the second embodiment, FIG. **16** is an explanatory diagram of the nozzles used to form the raster lines during each pass, within the effective printing area. Because the second embodiment uses a variable feed scheme, the positioning of the nozzle groups on each pass is not as regular as the first embodiment, the advantage of which is that the cumulative sub-scanning feed error is smaller than that of the first embodiment.

Another advantage of the second embodiment is that the accumulated error positions of adjacent nozzle groups are not always the same. In the case of cyan, the biggest difference in the sub-scanning feed passes is 4, between raster lines **2** and **3**. That is, there is a accumulated feed error Cmis between raster lines **2** and **3**. With respect also to magenta and yellow, accumulated feed errors Mmis, Ymis are located between raster lines **2** and **3**. However, the next Cmis and Mmis are between raster lines **8** and **9**, while the next Ymis is between raster lines **7** and **8**.

Thus, in the case of the second embodiment the accumulated error positions of the three working nozzle groups Cmis, Mmis, Ymis do not always coincide, so there is less banding compared to when the positions of Cmis, Mmis and Ymis always coincide.

FIG. **17** shows the actuator used in a second comparative example. The actuator **40**" is comprised of a group of 15 yellow nozzles **40Y**", a group of 15 magenta nozzles **40M**" and a group of 15 cyan nozzles **40C**". The spacing between the adjacent end nozzles of the groups is the same as the nozzle pitch k. The group of black ink nozzles **40K**" comprises 45 nozzles. The arrangement of the second comparative example uses this actuator **40**" to effect printing in accordance with the same scanning parameters as those of the second embodiment shown in FIG. **14**.

FIG. **18** is an explanatory diagram showing the nozzles used to form the raster lines during each pass, within the effective printing area, in the case of the second comparative example. The accumulated error positions Cmis, Mmis, Ymis of the three chromatic color inks fall between raster lines **2** and **3**, **8** and **9** and **14** and **15**. That is, in the second comparative example the accumulated error positions Cmis, Mmis, Ymis of the three colored inks always coincide and are repeated at six-dot intervals (that is, at the same pitch as the nozzle pitch k), making banding more noticeable.

As can be seen from a comparison between the working nozzles of FIGS. **15** and **17**, the only difference between the second embodiment and the second comparative example is the spacing between the groups of working nozzles. Specifically, in the case of the second embodiment the spacing between the groups is set at 2k (two times the nozzle pitch k) while in the case of the second comparative example the spacing is the same as the nozzle pitch k. This difference in the spacing between the groups of working nozzles is manifested in the differences in accumulated error positions Cmis, Mmis and Ymis seen in FIGS. **16** and **18**.

As in the first embodiment, the second embodiment uses a selection of working nozzles that results in the spacing between groups of working nozzles being M times the nozzle pitch k, where M is an integer of 2 or more. Also, the spacing between adjacent groups of working nozzles is set at a value other than $(N\times n+1)$ k dots where N is the number of working nozzles and n is an arbitrary integer of one or more.

As can be seen in FIG. **15**, the second embodiment uses all of the chromatic color ink nozzles of the actuator **40**. Since the spacing between implemented nozzle groups is set to twice the nozzle pitch k, even though all of the chromatic color ink nozzles are used, this does not result in the accumulated secondary feed error positions in respect of those inks constantly coinciding. The advantage of this is that using as many of the actuator **40**'s nozzles as possible makes it possible to print high-quality images.

It is desirable that the spacing between groups of implemented nozzles arrayed in the sub-scanning direction (that is, the spacing between the end nozzles of the adjacent groups of implemented nozzles used for each ink) be m times the nozzle pitch k (where m is an integer of two or more), since this enables the use of the most nozzles and thereby results in high print quality.

The spacing between the groups of implemented nozzles arrayed in the sub-scanning direction can also be set to be equal to the nozzle pitch k. In such a case, the working nozzle group configurations of the first and second embodiments can be implemented by not using some of the nozzles as working nozzles.

G. Actuator Variations

FIG. **19** shows a first actuator variation. In this actuator **41**, the nozzle array on the left is the same as the nozzle array on the left of the actuator **40** shown in FIG. **3**. The array of nozzles on the right of the actuator **41** of FIG. **19** includes a group of light magenta nozzles LM, a group of light cyan nozzles LC, and a group of black nozzles **40**K. The implemented nozzle group for each ink includes 15 nozzles. The spacing between the groups of implemented nozzles for the three colors arrayed in a straight line in the sub-scanning direction is 2k.

Light magenta ink has substantially the same hue as ordinary magenta ink but a lower density. This is also the case with respect to light cyan ink. Ordinary magenta ink and cyan ink are also referred to as dark magenta ink and dark cyan ink.

Color printing using this actuator **41** of FIG. **19** can be performed using the same scanning parameters used for the actuator **40** of FIG. **3**. Here, too, the accumulated error positions of the three nozzle groups **40**LM, **40**LC and **40**K on the right in FIG. **19** do not show much coincidence.

An advantage in using the actuator **41** of FIG. **19** is that it can use light-colored inks to thereby enable six-color printing, providing a better image quality than the actuator **40** of FIG. **3**. On the other hand, the actuator **40** can use about three times more black-ink nozzles than the actuator **41**, which gives the actuator **40** a high-speed monochrome printing capability.

When the actuator **41** of FIG. **19** is used, from the time point shown in FIG. **13** onward (that is, when sub-scan feeding is being effected by only the second sub-scanning drive mechanism **27**), yellow dots and light magenta dots are formed in the low-precision area LPA. Like yellow dots, light magenta dots are relatively inconspicuous, so the lower sub-scanning feed precision does not have much of an adverse effect on the image quality. Therefore the same feed amounts used when the paper is being fed by the first sub-scanning drive mechanism **25** can be used when the paper is being fed by just the second sub-scanning drive mechanism **27**.

As can be understood from FIG. **19**, when the paper is being fed in the sub-scanning direction by just the second sub-scanning drive mechanism **27**, in the low-precision area LPA it is desirable to form only dots of ink having a relatively low density. When only inks of the four colors cyan, magenta, yellow and black can be used, a relatively low density ink means yellow ink, and when dark and light inks can be used, it means a light ink (light cyan or light magenta, for example) as well as yellow ink.

FIG. **20** shows a second actuator variation. The difference between this actuator **42** and the actuator **41** of FIG. **19** is that the positions of the groups of light magenta nozzles **40**LM and dark magenta nozzles **40**M are transposed, as are the positions of the groups of dark cyan nozzles **40**C and light cyan nozzles **40**LC. This actuator **42** offers substantially the same advantages as the actuator **41**.

However, when the actuator **42** of FIG. **20** is used, from the time point shown in FIG. **13** onward, yellow dots and light magenta dots are formed in the low-precision area LPA. Therefore, from the standpoint of image quality within the low-precision area LPA, rather than this actuator **42**, it is preferable to use the actuator **41** shown in FIG. **19**.

FIG. **21** shows a third actuator variation. In this actuator **43**, the color nozzle array and black nozzle array **40**K of the actuator **40** of the embodiment shown in FIG. **3** are each disposed in a zigzag arrangement, with the odd-numbered black nozzles, as one example, on the left and the even-numbered nozzles on the right. The same type of zigzag arrangement is also used for the groups of chromatic color nozzles **40**Y, **40**M and **40**C. Even with this zigzag arrangement, the nozzles of the groups **40**Y, **40**M and **40**C are still arrayed along a straight line in the sub-scanning direction. Thus, the description "a plurality of nozzle groups are arrayed along a straight line in the sub-scanning direction" refers to the groups of nozzles being arrayed in what is a straight line in overall terms, not that the nozzles that comprise each group are necessarily in a straight line.

While each actuator of the above embodiments and variations has nozzles for four or six colors arranged in two arrays, the nozzles may instead be arranged in a single array, or in three or more arrays. For example, with respect to the actuator shown in FIG. **3**, 15 black nozzles could be provided below the groups of color nozzles, separated by a 2k gap, to thereby provide groups of nozzles for four colors, arranged in a single array.

It is also possible to use a print head in which the spacing between the groups of nozzles used for each color is set at the same value as the nozzle pitch k.

FIG. **22** shows a fourth actuator variation, comprising a first actuator **44***a* having just a color nozzle array and a second actuator **44***b* having just a black nozzle array **40**K. As in FIG. **21**, the nozzles are arranged in a zigzag configuration. The substantive difference from the actuator of FIG. **21** is that each color nozzle group has 16 nozzles and the spacing between the groups of color nozzles is equal to the nozzle pitch k.

FIG. **23** shows a fifth actuator variation. The actuator **45** includes three arrays of color nozzles and one array of black nozzles. A first array of color nozzles is comprised of a group of yellow nozzles **40**Y and a group of magenta nozzles **40**M. A second array of color nozzles is comprised of a group of light magenta nozzles **40**LM and a group of cyan nozzles **40**C. A third array of color nozzles is comprised of a group of light cyan nozzles **40**LC and a group of light black nozzles **40**LK. The term "light black" means gray, not solid black.

The groups of nozzles are each arrayed in a straight line in the sub-scanning direction, but may be arrayed in a zigzag arrangement as in FIGS. **21** and **22**. The black nozzle array **40**K has 48 nozzles, and each of the other nozzle groups has 24 nozzles. When the actuator **45** is used, only dots of relatively low density (yellow, light magenta, and light cyan dots) are formed in the low-precision area LPA, so there is little degradation in image quality.

FIG. **24** shows a sixth actuator variation. The actuator **46** also includes three arrays of color nozzles and one array of black nozzles. The difference between the actuator **46** and that of FIG. **25** is the positions of the nozzle groups other than the black nozzle group **40**K and the yellow nozzle group **40**Y.

FIG. **25** shows a seventh actuator variation. This actuator **47** has three nozzle arrays. The first array is comprised of a group of yellow nozzles **40**Y and a group of magenta nozzles **40**M; the second array is comprised of a group of light magenta nozzles **40**LM and a group of cyan nozzles **40**C; and the third array is comprised of a group of light cyan nozzles **40**LC and a group of black nozzles **40**K. When the actuator **47** is used, only dots of relatively low density are formed in the low-precision area LPA, so there is little degradation in image quality.

FIG. **26** shows a eighth actuator variation. This actuator **48** has a single line of nozzles arrayed in the sub-scanning direction, divided into six color groups. Each group has eight nozzles. Instead of being in a straight line, the nozzles of each group may be arranged in a zigzag configuration. When the actuator **46** is used, only dots of relatively low density are formed in the low-precision area LPA, so there is little degradation in image quality.

H. Modifications

(1) The above embodiments have been described with reference only to unidirectional printing in which dots are printed only during a forward pass in the main scanning direction. However, the invention can also be applied to bi-directional printing in which dots are printed during both forward and reverse passes.

(2) Depending on the printer, the dot pitch (printing resolution) in the main scanning direction and the dot pitch in the sub-scanning direction can be set at different values. In such a case, parameters relating to the main scanning direction (such as the pitch of pixels on the raster lines, for example) are defined by the dot pitch in the main scanning direction, while parameters relating to the sub-scanning direction (such as nozzle pitch k and feed amount L, for example) are defined by the dot pitch in the sub-scanning direction.

(3) The invention can also be applied to drum scanning printers, in which case the direction of drum rotation becomes the main scanning direction and the direction of carriage travel the sub-scanning direction. In addition to inkjet printers, the invention can also be applied to any printing apparatus that prints on media using a print head having an array of multiple dot formation elements. By dot formation element is meant a constituent element for forming dots, such as an ink nozzle in the case of an inkjet printer. A facsimile machine and copiers are examples of such printing apparatuses.

(4) While the structures of the above embodiments have been described in terms of hardware implementations thereof, the hardware may be partially replaced by software implementations. Conversely, software-based configurations may be partially replaced by hardware. For example, some of the functions of the system controller **54** (FIG. **2**) may be implemented by the host computer **100**.

Computer programs for realizing such functions may be provided stored on a storage medium that can be read by computer such as floppy disks and CD-ROM disks. The host computer **100** can transfer the program from the storage medium to an internal or external storage device. Alternatively, communication means may be used to send the programs to the host computer **100**. To effect program functions, the stored program can be executed directly or indirectly by the host computer **100**.

The host computer **100** as referred to herein is taken to include hardware and operating system, with the hardware functioning under the control of the operating system. Some of the above functions may be implemented by the operating system instead of an application program.

The storage media that can be read by computer referred to herein are not limited to portable storage media such as floppy disks and CD-ROM disks, but also includes internal storage and memory devices such as various types of RAM and ROM as well as external fixed storage such as hard disks.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the appended claims.

What is claimed is:

1. A print head for use in a printing apparatus that prints images by forming dots on a print medium, the print head comprising:

a first array of a plurality of dot formation element groups including, at a first end of the first array, a yellow dot formation element group for forming yellow dots; wherein:

the dot formation element groups are ordered in a sub-scanning direction such that at an arbitrary point on the print medium, the print head is configured to form yellow dots after forming any dots of colors other than yellow; and

when the printing apparatus feeds the print medium in the sub-scanning direction in a low precision mode that is lower in precision than a high precision mode, the print head is configured to print using only the yellow dot formation element group and not other dot formation element groups in the first array.

2. A print head according to claim **1**, further comprising:

a second array of a plurality of dot formation element groups, disposed parallel to the first array, having a group of black dot formation elements for forming black dots,

wherein the group of black dot formation elements is arranged at an end of the second array opposite the first end of the first array.

3. A print head according to claim **2**, wherein:

the first and second arrays have an identical number of dot formation element groups.

4. A print head according to claim **2**, wherein:

the second array includes a plurality of black dot formation elements disposed at same sub-scanning positions as the dot formation elements of the first array.

5. A print head according to claim **2**, wherein:

the first and second arrays are formed within a single actuator.

6. A print head for use in a printing apparatus that prints images by forming dots on a print medium, the print head comprising:

a first array of a plurality of dot formation element groups including, at a first end of the first array, a yellow dot formation element group for forming yellow dots; wherein:

the dot formation element groups are ordered in a sub-scanning direction such that at an arbitrary point on the print medium, the print head is configured to form yellow dots after forming any dots of colors other than yellow; and

when the printing apparatus feeds the print medium in the sub-scanning direction so that the print head is near a trailing edge of the print medium, the print head is configured to print using only the yellow dot formation element group and not other dot formation element groups in the first array.

7. A print head according to claim **6**, further comprising:

a second array of a plurality of dot formation element groups, disposed parallel to the first array, having a group of black dot formation elements for forming black dots,

wherein the group of black dot formation elements is arranged at an end of the second array opposite the first end of the first array.

8. A print head according to claim **7**, wherein:

the first and second arrays have an identical number of dot formation element groups.

9. A print head according to claim **7**, wherein:

the second array includes a plurality of black dot formation elements disposed at same sub-scanning positions as the dot formation elements of the first array.

10. A print head according to claim **7**, wherein:

the first and second arrays are formed within a single actuator.

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